THE COPPER MINES OF THE WORLD

BY

WALTER HARVEY WEED

GEOLOGIST, UNITED STATES GEOLOGICAL SURVEY, 1883–1906; MEMBER OF THE INSTITUTION OF MINING AND METALLURGY; FELLOW OF THE GEOLOGICAL SOCIETY OF AMERICA; MEMBER OF THE AMERICAN INSTITUTE OF MINING ENGINEERS; MEMBER OF INSTITUTION OF MINING ENGINEERS, ETC., ETC.

WITH ILLUSTRATIONS

NEW YORK AND LONDON
HILL PUBLISHING COMPANY
1907

Set up and electrotyped by J. S. Cushing Co., Norwood Press, Norwood, Mass., U.S.A.

PREFACE

COPPER is the most universally sought of the non-precious metals, as it has no equal as an electrical conductor, and is the basis of all brass and bronze alloys. It is, therefore, a matter of great and widespread interest to determine under what conditions it occurs, and what prospect there is that the supply will keep pace with the ever increasing demand; for, though found in many countries and numberless deposits, it occurs in paying quantities in comparatively few places.

To form a correct estimate of the value and character of a copper deposit it is necessary to know:

(1) Where are the deposits found? (2) What is the nature of the ore and its amenability to treatment? (3) How much of it is there? (4) What is the geologic occurrence; namely, its structural, mineralogical, and chemical relations? (5) What is the bearing of the observed facts on the probability of richness and continuity in depth? (6) What is the genesis of the deposit, and its bearing on the present and probable future production? These questions I have attempted to answer in this book.

In the first part of this work I have attempted to give a general account of copper deposits, with the broader features of distribution, geologic occurrence, nature of the ore, etc. In this I have not ventured into the broad fields of physical chemistry or metallurgy, nor is any attempt made to discuss the financial merits of particular properties. The deductions drawn are based upon the facts presented in the second part of this work. In that part an honest endeavor has been made to gather the evidence at first hand, so far as possible, or from the monographs of reliable investigators. "Facts are facts, to be used, to be studied, and to be studied and used again."[1] Their interpretation may be questioned and a different explanation given, but the facts must remain the same. The descriptive matter aims to give an account of only the world's most important mines, including those that are present producers, and others of importance because of their past history, or because their study enables one to make a more trustworthy diagnosis of newly dis-

[1] *Engineering and Mining Journal*, October 20, 1904, p. 623.

covered deposits. An attempt has been made to give precedence to practical matters. This may not always be apparent; but the fact has been clearly brought out, in recent study of ore deposits, that the genesis, structural relations, and the occurrence of secondary enrichments really determine the value of a deposit as well as its method of exploitation and the nature of the ore which it furnishes.

The present work is the outgrowth of the need felt by the author of a book presenting the known facts concerning the copper deposits of the world. It is confessedly in part a compilation; for, while the writer has seen almost all the big mines of the United States, Canada, and Mexico, which furnish two-thirds of the world's output, he has culled freely from the detailed studies of others for descriptions of them as well as of foreign districts. Much interesting matter concerning the lesser and economically unimportant deposits of Europe has been omitted in the attempt to present more than a scrap-book collection of mine descriptions, and to keep the matter written within a reasonable number of pages. Many important occurrences receive but short accounts, and many deposits of no present importance are fully described. The first circumstance is due to a lack of reliable information; the second, either to a belief in the future importance of the deposit or to a desire to prevent the waste of money on worthless properties.

No attempt is made to present the facts concerning the financial aspect of properties. For this purpose I recommend the "Copper Handbook," of Horace J. Stevens, which covers that field thoroughly, and should be owned by every one interested in copper-mining companies.

The reduction of copper ores is well and authoritatively treated in Peters' "Modern Copper Smelting"; and the reader is referred to that work for such information.

WALTER HARVEY WEED.

NEW YORK, March 1, 1907.

CONTENTS

PART I

GEOLOGY OF COPPER

CHAPTER I

CHAPTER II

CHAPTER III

CHAPTER IV

CHAPTER V

CHAPTER VI

CHAPTER VII

PART II

DESCRIPTIONS OF THE PRINCIPAL COPPER MINES OF THE WORLD

CHAPTER VIII

CHAPTER IX

CHAPTER X

CHAPTER XI

CHAPTER XII

CHAPTER XIII

ILLUSTRATIONS

PART I

GEOLOGY OF COPPER

I

DISTRIBUTION OF COPPER DEPOSITS

Deposits of copper are of world-wide distribution, being found in every continent and in nearly every country of the world. Despite this extensive distribution, the world's supply of this metal is practically derived from less than 250 copper mines. This is the number of mines whose annual production is as much as 100,000 lb. or more, representing a value of about $15,000. This seems a surprisingly small number when one considers that the United States alone has over 3000 copper-mining companies. Moreover, of the 250 mines the United States contains 58; Japan, 38; Chile, 31; and Australia, 28; the remaining 95 being scattered all over the world. The annual production of the last-named three countries is only about 30,000 tons apiece, and comes mainly from a few mines. The figures show that the bulk of the world's supply comes from about 170 mines, and of this three-fifths is furnished by five great mines, one mine alone furnishing one-fifth of the entire production. The United States is, of course, the greatest producer; Mexico ranks second; and the third greatest producer is Spain, whose orebodies, though low in grade, are enormous in size, are situated close to the sea, and are valuable for their sulphur contents. Germany, the largest user of copper next to Great Britain and the United States, contains but two large mines. Mexico and Canada are rapidly increasing their production; but, with the exception of these two countries and the United States, there is no immediate increase in production in sight.

There are three very different ways of grouping copper deposits for discussion:

1. The commercial grouping, in which they are treated in the order of their importance as producers.

2. By geographic distribution, in which the deposits of each country are brought together.

3. The systematic, in which the deposits are grouped and treated according to their structural relations, mineralogic character, etc.

[illegible] three methods of treat- [illegible] mines of the world, the [illegible] has been convenient to [illegible] types of deposits by the [illegible] best-known deposit of this [illegible] type is well known, and [illegible] Iberian Peninsula, but also [illegible] Germany, can be made the [illegible] through the list; if it is [illegible] peculiar deposits of small [illegible] interest, may be included. It is [illegible] in knowing in what amount [illegible] in each country, than in a [illegible] treatment of the subject. For this [illegible] followed in the second part of [illegible] of the world are described.

[illegible] not uniformly distributed over [illegible] individualized districts, often of slight [illegible] the deposits are bunched in a [illegible] deposits, productive or idle, were [illegible] would be very liberally peppered, [illegible] of the spots, which would cover [illegible] continent.

[illegible] copper deposits of the world is in- [illegible] the thirty-seven most important [illegible] shown and numbered. The great pro- [illegible] water or on railway lines; in fact, the [illegible] great copper property is hardly possible [illegible]

[illegible] gold and silver ores, the accompanying [illegible] the United States Fig. 2 is interesting. [illegible] erroneous impression, however; for it is [illegible] deposit that is worthy of attention, and the [illegible] of importance there are in the United [illegible]

[illegible] the development of many Australian [illegible] state railways. Desert [illegible] condi- [illegible] transportation [illegible] effective [illegible] is per-

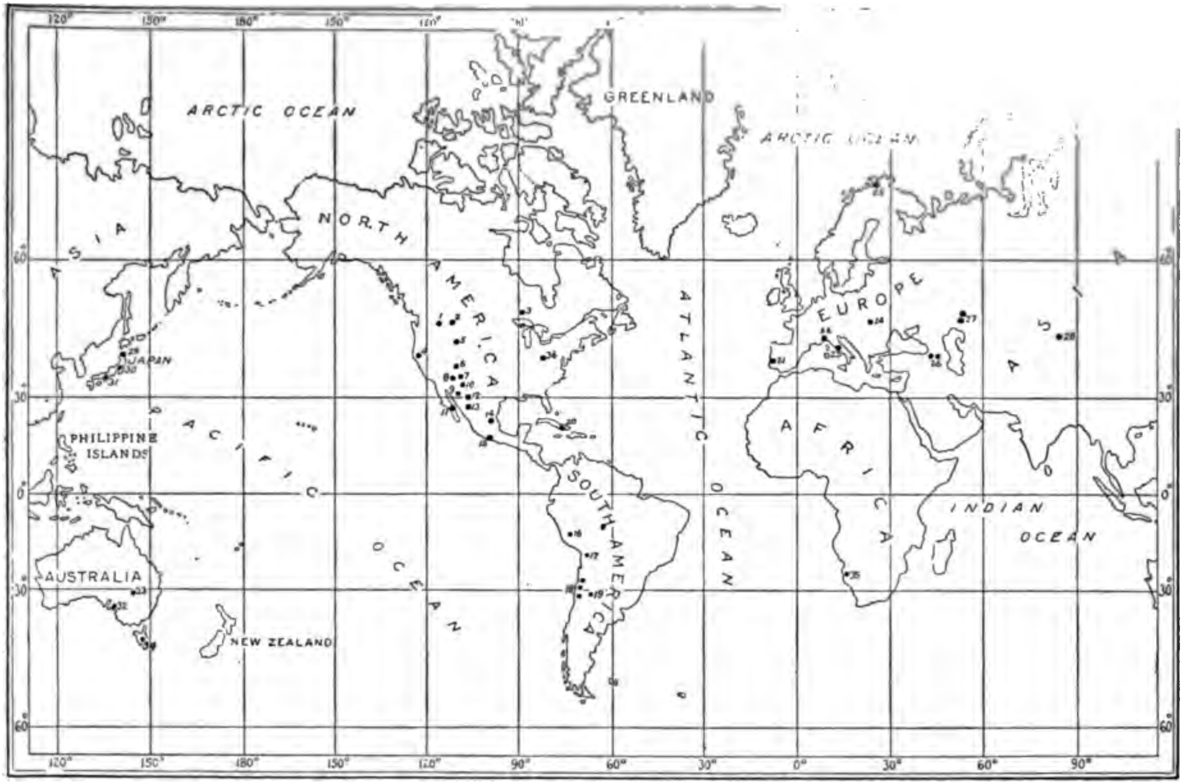


FIG. 1.—MAP SHOWING DISTRIBUTION OF COPPER DEPOSITS OF THE WORLD

1. Boundary District, British Columbia. 2. Rossland, British Columbia. 3. Sudbury Nickel-Copper Mines, Ontario, Canada. 4. Shasta County Copper Belt, California. 5. Butte, Montana. 6. Bingham, Utah. 7. Globe, Arizona. 8. Jerome, Arizona. 9. Bisbee, Arizona. 10. Morenci, Arizona. 11 Boleo, Lower California, Mexico. 12. Cananea, Sonora, Mexico. 13. Nacozari, Sonora, Mexico. 14. Teziutlan, Mexico. 15. La Dicha, Guerrero, Mexico. 16 Cerro de Pasco, Peru. 17. Coro Coro, Bolivia. 18 Chilean Mines 19. Famatina District, Argentine Republic. 20. El Cobre, Santiago, Cuba. 21. Rio Tinto, Spain. 22. Libiola Mines, near Genoa, Italy. 23. Monte Catini Mines, near Leghorn, Italy. 24. Mansfeld, Germany. 25. Sulitelma, Norway. 26 Kedabeg, Caucasus, Russia. 27. Miednorusk, Ural Mountains, Russia. 28. Spassky Mines, Akmolinsk, Siberia. 29. Kosaka, Japan. 30. Ashio, Japan. 31. Besshi, Japan. 32. Wallaroo and Moonta, Australia. 33. Cobar, Australia. 34. Mount Lyell, Tasmania. 35. Cape Copper Mines, Namaqualand, Cape Colony, Africa. 36. Ducktown, Tennessee.

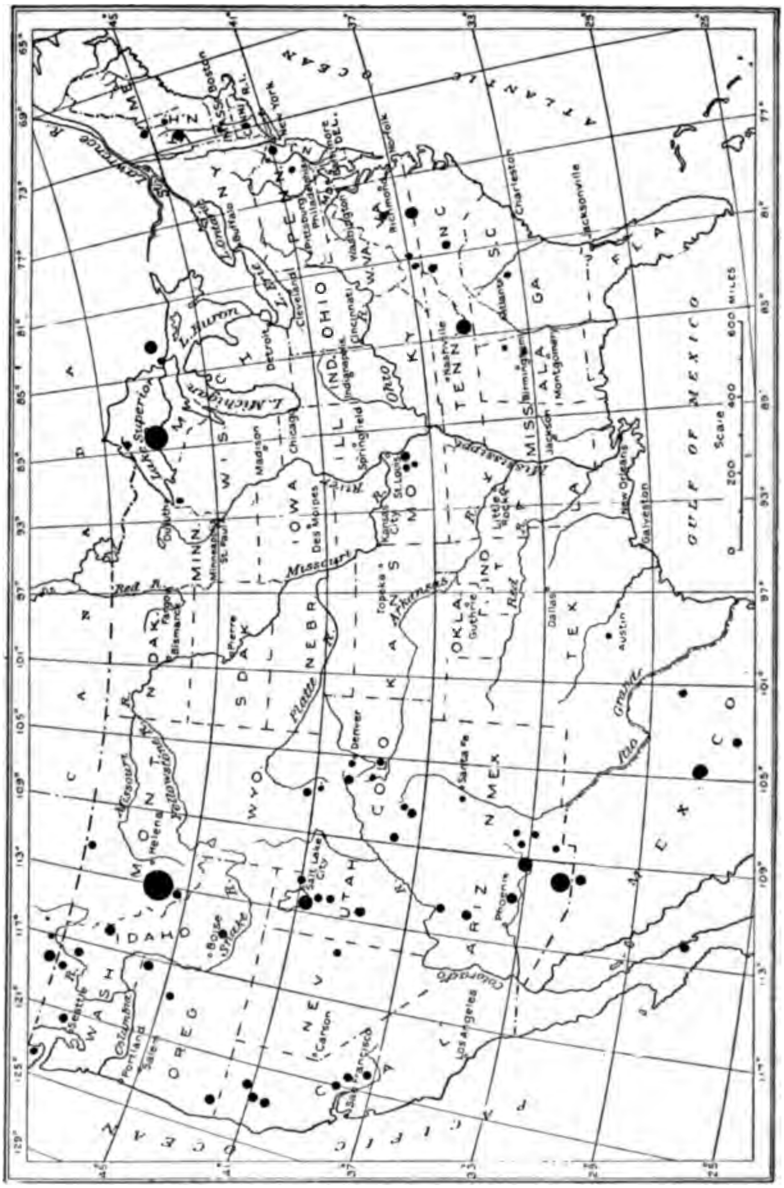


FIG. 2.—DISTRIBUTION OF COPPER IN THE UNITED STATES

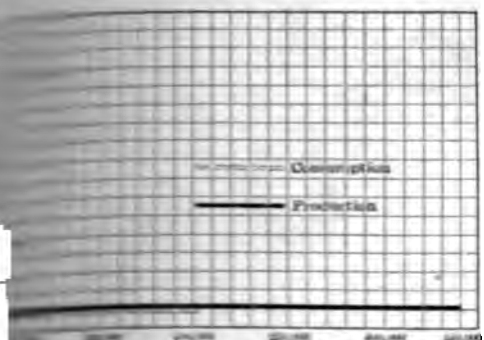
haps the most stupendous and costly piece of railway ever built, and it was mainly for mining development; while in Argentina the government has lately spent $1,500,000 in building a 22-mile aërial rope tram, with a difference in elevation of 11,000 ft. between terminals, to bring copper ores to the railway and smelter.

While it is true that a great deposit will not have to wait for a railway, as the latter will be built to it if the distance be not great, yet there are many regions where extensive and probably valuable deposits are known, as, for example, the Congo region, where development must await cheap transportation. The exceptionally rich ores of Chile were able to stand transportation on the backs of llamas, but the greater bodies of low-grade ore are not workable under such conditions.

The only very extensive copper-bearing areas are those in which the metal is found in sedimentary rocks. The Kupferschiefer of Germany underlies a shallow basin 85 miles wide and 120 miles long. The Permian red beds west of the Urals carry copper for 300 miles in gradually lessening proportions, as the distance from the mountains increases.

Copper deposits are practically confined to certain fairly defined belts or zones, in or along which the copper districts occur. The Huelva zone of southwest Spain is well known; the California deposits occur along the foothill belt of the Sierras and in Shasta county; the famous Arizona deposits are localized in the Sonoran province, embracing eastern Arizona and Sonora; the Ural deposits lie along the flanks of that range; and the Andean region is ore-bearing for almost its entire extent. This geographical distribution and localization corresponds closely, but not wholly, to that of mountain folding, with igneous intrusions. The investigation of deposits in metamorphic schists, such as those of the Appalachian region and of Norway, also shows a usual dependence upon igneous rocks, now altered and disguised. This is more fully discussed later.

...tons, for which almost com-
...estimated at 715,268 metric tons
...the United States produced ap-
...next, but was far behind as a
...that of the United States.
...production and consumption
...seen that the United States not
...of the world put together, but ac-
...countries put together, if we
...not only owns the gold mines
...most of the copper as well. The
...about 700,000 metric tons.



...METRIC TONS THE PRODUCTION AND CON-
...IN EACH COUNTRY FOR 1905

South America as well. China, though possessing abundant deposits, is a large importer. The United States produced 378,000 metric tons in 1904, exporting 255,934 tons to Europe and 6800 tons to Asia, leaving 115,266 tons for domestic consumption.

The production of the world for the past ten years is given in Table I.[1]

TABLE I

COPPER PRODUCTION OF THE WORLD.[1]

(Long Tons)

COUNTRY	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906
EUROPE										
Great Britain	520	640	635	650	532	480	535	495	715	500
Spain and Portugal										
Rio Tinto	33,900	33,705	34,370	35,732	35,348	34,480	35,810	33,480	32,280	34,100
Tharsis	[a]11,000	[a]11,150	9,448	7,965	7,427	6,710	6,320	5,620	4,345	4,740
Mason & Barry	[a]4,300	3,600	3,600	3,460	3,729	3,330	2,430	2,950	2,720	2,465
Sevilla	810	800	1,200	1,460	1,292	1,545	1,105	1,330	1,280	2,040
Other mines	3,050	3,120	3,550	4,255	5,825	3,725	4,075	3,655	4,185	5,975
Germany:										
Mansfield	17,960	18,045	20,785	18,390	18,780	18 750	18,975	18,735	19,565	17,810
Other German	2,185	2,040	2,675	2,020	2,940	2,855	2,230	2,310	2,595	2,530
Austria	1,210	1,110	915	865	1,015	1,015	1,055	1,275	1,175	1,225
Hungary	445	430	590	490	320	485	330	175	150	210
Sweden	545	480	520	450	450	455	455	390	550	500
Norway	3,450	3,615	3,610	3,935	3,375	4,565	5,915	5,415	6,305	6,120
Italy	3,480	2,965	2,965	2,955	[a]3,000	3,370	3,100	3,335	2,950	2,865
Russia	6,025	6,260	7,210	6,740	[a]8,000	8,675	10,320	10,700	8,700	10,490
Turkey	975	470	920	520	980	1,100	1,400	950	700	425
Total	89,855	88,430	92,993	89,887	93,013	91,540	94,055	90,815	88,215	91,995
NORTH AMERICA										
United States	216,060	234,271	262,206	263,502	265,250	292,870	307,570	365,050	380,120	408,475
Canada	5,905	8,040	6,730	8,500	18,800	17,485	19,320	19,185	20,535	25,460
Newfoundland	1,800	2,100	2,700	1,900	2,000	2,000	2,060	2,200	2,280	2,295
Mexico:										
Boleo	10,170	9,435	10,335	11,050	10,795	10,785	10,315	10,945	10,185	10,830
Other Mexican	[a]3,200	[a]7,000	[a]9,000	[a]11,000	19,635	[a]25,000	[a]35,000	[a]40,000	54,255	49,795
Cuba	......	......	......	......	......	......	......	......	......	......
Total	237,135	260,846	290,971	295,952	316,480	348,140	374,265	437,380	476,375	496,855
SOUTH AMERICA										
Chile	21,900	24,850	25,000	25,700	30,780	28,930	30,930	30,110	29,165	25,745
Bolivia: Coro Coro	2,200	2,050	2,500	2,100	[a]2,000	[a]2,000	2,000	[a]2,000	[a]2,000	[a]2,500
Peru	1,000	3,040	5,165	8,220	9,520	7,580	7,800	6,755	8,625	8,505
Argentina	200	125	65	75	85	240	135	155	155	105
Total	25,300	30,065	32,730	36,095	42,385	38,750	40,865	39,020	39,945	36,855

[1] As reported by Henry R. Merton & Co., of London.

	1905	1906
	415	440
	5,025	3,040
	2,300	2,0[illegible]
	7,740	6,980
	35,010	42,740
	34,040	36,250
	682,125	711,675

II

PRODUCTI…

THE world's production of copper … plete statistics are now available, is … or 1,576,450,672 lb. Of this amou… proximately 55 per cent; Mexico … producer, with a total product of on… Figure 3 shows in metric tons the re… of each country for 1903. It will … only produces more than all the r… tually consumes as much as all the … except Great Britain. The Eng… of the world, but owns and cons… world's production for 1905 wa…

…ease in the world's … ited States 148 per

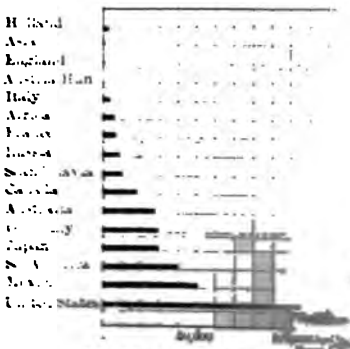


FIG. 3. DIAGRAM SHOWIN… SUMPTION OF

The diagram (Fig. 3) … produced by the Unit…

… the production of copper has been due to … mining in the United States, Mexico, and

… rates this fact.

TABLE II

…ODUCTION OF THE WORLD, 1899-1905
(Long Tons)

	World's Production	North America	Other Countries
……………………	463,093	282,636	181,057
……………………	486,009	303,784	183,215
……………………	517,865	320,044	197,821
……………………	548,604	355,280	193,324
……………………	585,461	384,138	201,323
……………………	648,924	445,557	203,367
……………………	682,725	496,855	185,870

…copper mines of the world and their production for …5 are given in Table III.

TABLE III

	1904	1905		1904	1905
……	90,000,000	95,443,730	Tamarack………	14,961,885	15,824,008
… Montana.	94,000,000	90,000,000	Champion………	12,212,954	15,707,426
… & Hecla..	80,341,019	83,812,370	Utah Consolidated..	13,553,493	17,264,474
…o………	80,214,400	72,307,200	Butte & Boston….	12,000,000	15,000,000
Queen….	58,605,000	64,570,847	Kosaka…………	12,505,000	15,868,000
… Consolidated	55,014,339	64,211,895	Ashio…………	14,622,000	15,428,000
…ld………	41,629,349	43,824,141	United States……	12,000,000	15,841,667
… Verde……	29,500,000	35,000,000	Granby…………	13,431,236	17,843,390
… Copper Co..	35,311,853	27,081,350	Baltic…………	12,177,829	14,384,684
…a………	32,197,760	26,830,000	Bingham……….	11,500,000	14 396,269
…met & Arizona.	31,634,895	32,772,896	Wallaroo & Moonta	13,070,952	14,562,240
… Dominion and United Globe…	15,368,147	32,000,000	Mitsu Bisshi……	12,500,000	12,727,944
			Besshi…………	12,000,000	12,500,000
…ginal………	20,500,000	18,000,000	Shannon……….	11,899,920	11,027,453
North Butte……	………	30,054,788	Parrot…………	12,500,000	12,000,000
Boleo…………	24,517,356	22,817,610	Tharsis…………	12,590,226	11,500,000
Trenton & Washoe	………	20,000,000	Trimountain…….	10,211,230	10,476,462
Quincy………	18,343,160	18,827,557	MountainCopperCo.	19,116,160	10,000,000
Detroit………	16,623,251	14,692,421	Lota y Coronel….	10,000,000	9,000,000
Osceola………	20,472,429	18,938,965	Moctezuma…….	9,632,000	10,800,000
Mount Lyell……	18,462,080	18,502,000	Guggenheim Exploration Co. ….	6,000,000	10,000,000
Cape Copper……	17,192,000	16,358,720			

TABLE IV

TOTAL COPPER PRODUCTION OF THE UNITED STATES, 1893-1906

(Pounds)

SOURCE	1893	1894	1895	1896	1897
Lake Superior	112,605,078	114,308,870	129,330,749	143,524,069	145,282,059
Arizona	43,902,824	44,514,894	47,953,553	72,934,927	81,530,735
Montana	155,209,133	183,072,756	190,172,150	221,918,179	230,288,141
New Mexico	280,742	31,884	143,719	2,701,664	701,892
California	239,682	120,000	218,332	690,237	11,987,772
Utah	1,135,330	1,147,570	2,184,708	3,502,012	3,919,010
Colorado (copper smelters [a])	7,695,826	6,481,413	6,079,243	6,022,176	11,873,033
Nevada	20,000	....	....	....	....
Idaho	36,367	....	1,425,914	....	183,277
South Dakota	....	....	....	....	2,440,338
Washington	39,785	....	....	....	....
Vermont / Tennessee and Southern States	732,793	2,374,514	3,105,036	4,704,993	4,472,017
Lead desilverizers, etc. [b]	7,456,838	2,136,473	....	4,063,173	1,400,000
Total domestic copper	329,354,398	354,188,374	380,613,404	460,061,430	494,078,274
From imported pyrites and ores and matte	10,431,574	10,678,434	[c] 5,300,000	[c] 5,900,000	[c] 12,000,000
Total (including copper from imported pyrites)	339,785,972	364,866,808	385,913,404	465,961,430	506,078,27

[a] Copper smelters in Colorado, purchasing argentiferous copper ores and mattes in the open market, sources not known. The quantity of Montana matte which goes to one of these works has been deducted.

[b] For 1896 the quantity stated covers only that part of the incidental copper product the source of which could not be ascertained.

[c] Estimated.

The copper industry of this country practically began in 1850, in which year the total production amounted to 650 tons, of which 572 tons came from the newly opened deposits of Michigan. Ten years later the product was more than ten times as great, the total being 7200 tons, according to the census returns, 5492 tons coming from Michigan, and the balance from the "black copper" ores of Tennessee. In 1870 the Lake Superior mines furnished 86 per cent, and Vermont the next largest percentage of the total of 12,600 tons. In 1880 the Arizona mines became an important factor, though it was not until three years later that the supremacy of the Lake mines began to appear doubtful, having fallen from 82 to 51 per cent of the total in that period.

The Montana mines produced 21 per cent of the total in 1883, the year which marks the discovery of the fact that the Anaconda, instead of being a low-grade silver mine, had a stupendous vein of copper glance ore, so large and so rich that, as Dr. Douglas has said, it began to

TABLE IV (*Continued*)

SOURCE	1898	1899	1900	1901	1902	1903	1904	1905 *e*	1906 *e*
Lake Superior	158,491,703	147,400,338	145,461,498	156,289,481	170,600,228	192,400,577	208,329,130	218,999,759	224,071,000
Arizona	111,158,246	133,054,860	118,317,764	130,778,611	119,944,944	147,648,271	191,602,248	222,866,020	263,200,000
Montana	206,173,157	225,126,855	270,738,489	229,870,415	288,903,820	272,555,854	298,314,804	319,179,880	299,850,000
New Mexico	1,592,371	3,935,441	4,169,400	9,629,884	6,614,961	7,300,832	5,368,666	5,638,843	6,262,000
California	16,925,634	26,221,897	28,511,225	33,667,456	25,038,724	17,776,756	28,529,023	16,697,486	24,421,000
Utah	3,750,000	9,584,746	18,354,726	20,116,979	23,939,901	38,302,602	47,062,880	51,950,782	49,712,000
Colorado [a]	16,274,561	11,643,608	7,826,949	9,801,783	8,422,030	4,158,368	9,506,944	9,854,174	9,565,000
Alaska	....	....	....	....	....	1,339,590	2,043,586	4,703,609	8,700,000
Wyoming	233,044	3,104,827	4,203,776	2,698,712	889,228	1,023,189	3,565,629	2,393,201	146,000
Nevada	437,396	556,775	407,535	593,608	164,301	150,000	23,317	*d*	*d*
Idaho	1,266,920	110,000	290,162	480,511	227,500	778,906	2,158,858	6,500,005	9,493,000
South Dakota	1,261,393	17,020	15,147	753,510	445,663	173,202	100,000	*d*	*d*
Washington	....	....	....	....	209,297	80,758	663,694	*d*	*d*
Vermont, North Carolina, Tennessee	5,395,226	4,410,554	4,820,495	6,860,039	13,599,047	13,855,612	15,211,086	14,907,982	18,821,000
Other States	....	....	....	....	....	....	....	1,550,000	3,379,000
Lead desilverizers, [b]	3,553,336	3,500,000	3,000,000	531,530	500,000	500,000	100,000	....	....
Total domestic	526,512,987	568,666,921	606,117,166	602,072,519	659,508,644	698,044,517	812,537,267	875,241,741	917,620,000
From imported ores and matte	[c] 19,750,000	[c] 23,800,000	[c] 36,380,000	[c] 64,000,000	[c] 40,000,000	[c] 32,000,000	38,947,772	38,947,772	....
Grand Total	546,262,987	592,466,921	642,497,166	666,072,519	699,508,644	730,044,517	851,485,039	914,189,513	....

[a] Copper smelters in Colorado, purchasing argentiferous copper ores and mattes in the open market, sources not known. The quantity of Montana matte which goes to one of these works has been deducted.

[b] Since 1901 the quantity stated covers only that part of the incidental copper product the source of which could not be ascertained.

[c] Estimated.

[d] Included under other States.

[e] As reported by *The Mineral Industry*.

disorganize the copper market of the world. The Anaconda reduction works were, however, not started until 1884, treating, what was then a very large amount, 600 tons of ore a day. These were enlarged again and again, until finally it was necessary to build entirely new works on another site, which are now treating 8500 tons a day.

Meantime in Arizona the Copper Queen at Bisbee had been developed, followed very soon after by the mines of the Clifton, Globe, and Jerome districts, the great producers of the territory today. The Arizona product, however, declined from 10,658 tons in 1883 to 6990 tons in 1886, a thousand more in 1887, with a jump to 14,195 in the following year. In 1890 Montana and Michigan produced nearly equal amounts, the combined product being 100,000 out of a total of 126,839. In 1900 Montana's production was far in the lead, a position it has kept despite the marvelous increase in the production of the Copper Queen and the opening of the new mines of the Bonanza Circle group at Bisbee.

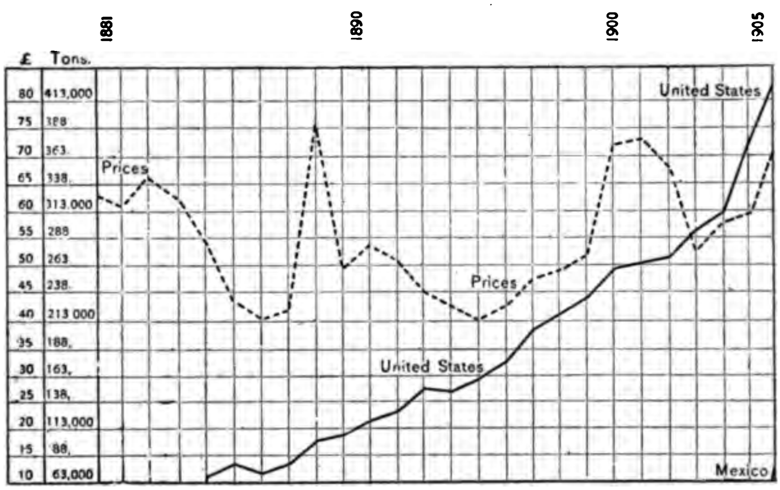


FIG. 5.—UNITED STATES COPPER OUTPUT FROM 1881 TO 1905

Since 1892 the annual increase in production has shown remarkable variations. In that year it was 21 per cent, but showed a decrease in the following year. In the next seven years it was about 7 per cent, except in 1896, when it was again 21 per cent. In 1901 the output showed a slight decrease, and in the next year the increase was only 1½ per cent. In the next year the increase jumped to 9½ per cent, and in 1904 to a little over 15 per cent. For 1905 the increase has been 135,363,000 lb., or about 18 per cent.

In considering the enormous production of the United States, it must be remembered that the mines are, relatively speaking, young and are still in the bonanza ores of the upper levels. Also, that in America mining is done in prodigious haste, and, according to European standards, the mines are often robbed. A great output and a great dividend for a few years, rather than a moderate output and dividend for many years, is the difference between American and European practice, justified in this country by the opportunity for reinvestment, or perhaps by the view that mining shares are not investments, but ventures. Table IV shows the production, by States, for 1893 to 1906.

The copper mines of the United States yield gold and silver as by-products, and some gold ores yield small amounts of copper. The total gold and silver production of the copper mines for 1904 was 237,116 and 15,769,327 ounces respectively, distributed as shown in Table V.

TABLE V

PRECIOUS METALS CONTAINED IN THE COPPER ORES OF EACH STATE

	OUNCES GOLD	OUNCES SILVER
Utah	109,968	2,572,582
Arizona	47,563	1,464,731
Montana (Butte)	44,400	10,236,119
California (Shasta)	24,727	844,265
New Mexico	4,137	79,369
Colorado	3,288	131,695
Appalachian States	[a] 1,066	[a] 79,600
Washington	582	16,710
Idaho	538	201,843
Wyoming	326	4,601
Oregon	326	11,697
South Dakota	145	789
Nevada	10	2,519
Michigan	140	122,807
Totals	237,116	15,769,327

[a] Estimated.

PRICE PER POUND

The highest and lowest prices obtained for Lake Superior copper, yearly, in the New York market from 1860 to 1905 are enumerated in Table VI.

disorganize the copper market of the world. The Anaconda works were, however, not started until 1884, treating, what very large amount, 600 tons of ore a day. These were enl and again, until finally it was necessary to build entirely on another site, which are now treating 8500 tons a day.

Meantime in Arizona the Copper Queen at Bisbee had b followed very soon after by the mines of the Clifton, Glol districts, the great producers of the territory today. product, however, declined from 10,658 tons in 18 in 1886, a thousand more in 1887, with a jump to 14,1 ing year. In 1890 Montana and Michigan produ amounts, the combined product being 100,000 126,839. In 1900 Montana's production was far in it has kept despite the marvelous increase in the Copper Queen and the opening of the new mi Circle group at Bisbee.

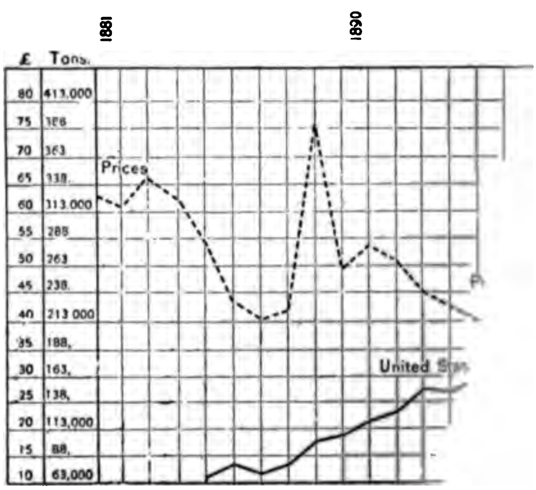


FIG. 5.—UNITED STATES COPPER

Since 1892 the annual increase in variations. In that year it was 21 pe following year. In the next seven y in 1896, when it was again 21 per slight decrease, and in the next ye. In the next year the increase jum

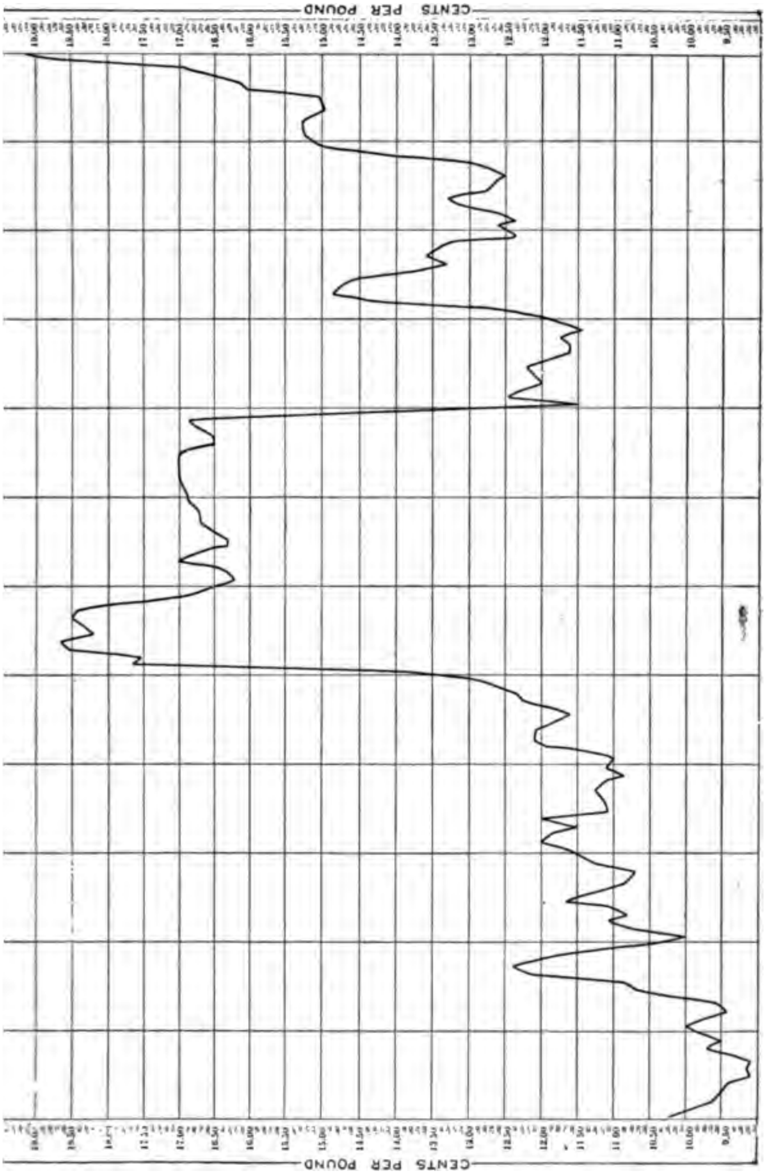


FIG. 6. — DIAGRAM SHOWING VARIATION IN PRICE OF COPPER

Some of the Huelva mines of southern Spain, worked since Roman days, are already exhausted; the Rio Tinto ores are gradually getting leaner and leaner, and the region is barely holding its own as a copper producer, despite the prevailing high prices. The Montana mines have increased their output to nearly 20,000 tons of ore a day, and several mines are 2400 ft. deep: they cannot last forever; and the district must see a decline some day, though fortunately it is not yet in sight.

Lake Superior will hold its own for many years to come, owing to the opening of new mines; but the older ones, the best payers, are already a mile deep, and working costs, if not leaner ore, will limit their downward extension.

Europe, Asia, Australia, and Africa produce copper, but the production is stationary or declining. South America is said to have untold wealth in copper, but the economic conditions are so unfavorable that, with the exhaustion of the rich secondary ores, the deposits are often abandoned.

The present and future increase will, it is believed, come from North America; first from Nevada, Utah and Mexico; next from British Columbia and Alaska.

Copper mining is becoming a more stable industry with the development of great bodies of low-grade ore, rather than the rich but usually limited deposits of the earlier stages of mining. The development and operation of low-grade deposits necessitates large plants, cheap fuel, and cheap transportation, as well as a very large amount of invested capital. In undeveloped and remote regions it is only the very rich ores that can yield a profit, and hence in the opening up of a new country or section, as in western North America, central Africa, and Asia, the low-grade deposits are the last to be developed.

In estimating the copper resources of a country (a problem which is regarded as outside of the province of this book, in which only the mines industrially or scientifically important can be considered), it is necessary to take into account all the known facts concerning old and abandoned copper mines; not only the small deposits worked until their small extent caused their abandonment, but the once great mines. Altered conditions of treatment, or cheapened fuel or transportation, may render these old deposits valuable, particularly in old countries like Turkey, Persia, China, etc. The renovation of the Japanese mines is a case in point, while Australia and America also furnish examples. The size of the deposit is perhaps the most important factor; for 1½ per cent ore, as in the Bingham district, or even 1 per cent ore, may sometimes, as at Lake Superior, prove immensely valuable. The nature of the matrix may be the determining factor, as is the case with the solid pyrite ores of the Spanish deposits, also at Mount Lyell and Great Cobar; or the copper content may pay all costs and leave the gold value as profit. Thus the complex, impure, sulphide ore of the Lake George mine (N.S.W.), carrying but 1.11 per cent copper and 20 per cent silica, with very low values in gold and silver, was concentrated in smelting 27 tons ore to one of 30 per cent matte, and profitably treated, the total cost of mining, smelting, and general expenses being but 14*s.* 9*d.* per ton.[1]

How low a grade of ore can be profitably worked depends upon local conditions and the nature of the ore. If gold and silver be present, even in small amount, an ore, capable of raw pyritic smelting, and carrying but 2 per cent, can be treated at a profit, as at Ducktown (Copperhill), Tenn. Ore that is readily concentrated, like that of Butte, with glance grains in rotted granite, may also be cheaply treated by preliminary wet concentration, 2.6 per cent ore being the average for 1905 at Butte. At the Boundary Creek district, B.C., the net yield of the Mother Lode ores was 21 lb. copper and $1.14 gold and silver, in 1904–1905.

In copper mining the prime factor in determining the cost is the amount of copper in the ore. In treating it the cheapest possible process must be used. In many cases this is wet concentration, despite the enormous losses incident thereto. Where the nature of the ore makes this impracticable, direct smelting and reconcentration in matte is practiced.

Cost depends also upon character of gangue. When ore is self-fluxing this cost becomes cost per ton of ore, as at Boundary, where it is $1.60 per ton. When only 80 per cent of charge is ore, as is general practice in the Rocky Mountain region when flux is added the cost per ton of ore is raised to about $3.20.

The use of silicious gold and silver ores as fluxes for pyritic ores, and as converter linings, may turn the scale and render an otherwise worthless ore profitable. Abundance and a kindly matrix are the essential conditions for the profitable working of low-grade deposits. The Boundary Creek (B.C.) deposits fulfill these conditions. They are large, cheaply workable, and have a self-fluxing matrix.

The composition of the matrix is very important. If silicious, the infusibility and necessity of about 2 lb. of basic flux for each 1 lb. of silica is a serious detriment. The silica content should be about 24 per cent, although in pyritic ores 30 to 40 per cent can be treated.

[1] Carne, "Copper Mines of New South Wales," p. 19.

The remarkable cheapening of the cost of production made in recent years as a result of bessemerizing, mechanical roasting and handling of ores, and of raw smelting, has revolutionized copper smelting by making low-grade ore available, and thus enormously increased the ore reserves of many localities. Expert metallurgists predict the profitable working of 1 per cent sulphide ores; and the use of magnetic separators[1] may make available ores that thus far have been unprofitable. Electrolytic refining of copper pig has not only permitted an easy means of recovering the precious metal content of copper ores, but has largely eliminated the bugbear of arsenic, antimony, and bismuth, those frequent and despised associates of the red metal in so many ores.

The practice inaugurated by Heywood at the Pittsmont smelter at Butte is a near approach to chemical theory. With ores carrying 75 to 90 per cent SiO_2, mixed with one-fifth their weight of pyrrhotite ore carrying gold, and 8 per cent coke, a 4 per cent ore is treated raw (with limestone flux), producing an 18 to 20 per cent matte, that is bessemerized in a basic-lined converter, adding raw ore as flux.

Cost of Mining Copper Ore

The effect of special conditions in determining the mining cost cannot be better shown than by comparing Butte, whose well-equipped and developed mines have a mining cost of $3.50, with the Atlantic of Michigan, where the cost is 90c., the Granby (B.C.) about 96 c., and Tennessee Copper Comapny (1902), 84 c. At Globe, Arizona, the mining cost is $5.00 per ton of ore.

A table of costs, given in the report of the Shannon Copper Company of Morenci, Arizona, for 1905, shows the following items:

Development	$3.46 per foot for 11,931 ft.
Sinking	3.27 per foot for 2810 ft.
Operating expenses, total	9.87 per pound.

In open-cut work the expense for mining was $2.138, distributed as follows:

Mining	$0.932	Tramming	$0.111	Filling	$0.056
Timber	.501	Development	.217	Sampling and assay	.048
		Miscellaneous	.273		

These costs apply to a production of 53,353 tons of 5.15 per cent smelting ore (42 per cent of output) and 135,503 tons of concentrating ore (3.66 per cent).

[1] *Mining Magazine*, June, 1905, p. 519.

The Bingham costs are much lower. Mr. Samuel Newhouse submits the following figures for the Boston Consolidated:[1] Total cost of mining, milling, smelting, and refining, etc., $1.78 on a 1.4 per cent ore, of which 75 per cent is recovered by wet concentration (at 13½ c. = $2.83 per ton + 20 c. for gold and silver, a total value of $3.03).

Value and Character of Ores

The ores of copper may be commercially grouped as (1) native, (2) oxide, (3) pyritic, and (4) complex impure ores.

The first is produced in quantity at Lake Superior only, though South America has furnished considerable quantities from the oxide zone. The Lake ores, occurring in large bodies, can be mined, melted, and cast for less cost than any other variety, and hence .75 per cent ore is worked at a profit.

The oxide ores exist in large bodies of low-grade ores, and may be an important source of copper. Those rich enough to mine are now mixed with sulphide, or, as at Boleo, smelted with gypsum and matted.

The pyritic ores are widely sought, and occur commonly in great ore-bodies. Where there is little gangue, as at Mount Lyell, Ducktown, Tasmania, etc., pyritic smelting affords profitable treatment of as low as 1.9 per cent ores, even where gold and silver are *nil*.

The sulphide ores in self-fluxing gangue, as at Boundary, B.C., are a variation, in which 2 per cent ore is worked profitably.

The complex ores in which copper, lead, and zinc sulphides occur together are most troublesome and costly to treat; but as these ores always carry gold and silver they are profitable. The cheapest treatment of such ore known is at Lake George, N.S.W., Australia, where 1.11 per cent copper ore, high in lead and zinc, is mined, smelted, and marketed for $2.54 per ton, yielding a small margin of profit.

[1] *Engineering and Mining Journal*, July 6, 1905, p. 33.

III

MINERALOGY OF COPPER

A COPPER ore may be commercially defined as any rock or mineral mixture containing copper enough to mine and extract at a profit. Inasmuch as the limit of profitable working has varied from time to time, material is called "ore" even if it is too low-grade to work, so that the definition does not strictly accord with current usage. For convenience it is better to discriminate ore minerals, meaning those minerals containing the metal to be mined, and gangue minerals, meaning the earthy and generally worthless associates of the metallic minerals.

Copper ores consist, as a rule, of a mixture of one, two, or more copper-bearing minerals and the gangue. The latter may be merely altered country rock, or it may be introduced vein-filling minerals. The mixture may consist of almost pure ore mineral, or it may carry so little of the ore mineral as to appear to be waste. The concentrating ores of Morenci, Butte, etc., look like rotted, barren granite.

In actual practice only a few of the many copper-bearing minerals are found in commercial quantities. These will be first described, and then a list given of the less common minerals, which will be found convenient for reference. In the brief account of the minerals of commercial importance they have been given in alphabetical order, and not in the order of their importance as ores. As technical descriptions can be found in any standard text-book on mineralogy, only the briefest mention of the physical characters are given herein. The aim of this chapter is to present a readily understandable account of the composition and main features of the minerals important as copper ores, with such notes on the occurrence, association, and physical character of these minerals as are of general interest.

COPPER-BEARING MINERALS

Of [illegible] minerals, or those which, though com-
r [illegible] to be of commercial importance, a large

part are of secondary origin, and formed in the weathering and oxidation of sulphide ores. A few of the oxide minerals are, it is true, important as ores; namely, the green and blue carbonates, malachite and azurite, the red oxide, cuprite, and the silicate, chrysocolla. Some of these minerals are almost always present in the weathered part of copper deposits. Of the minerals most important in mining, copper glance is essentially a secondary ore almost always found below the gossan, either above the unaltered pyritic ores or along fracture planes and water channels extending down into the primary ore. It rarely occurs under conditions which indicate a primary origin. The great secondary enrichments which form the bonanza orebodies of copper mines are largely composed of this material.

Copper occurs native and combined with sulphur, selenium, tellurium, manganese, arsenic, and antimony, the compounds with the substances mentioned being found beneath the weathered zone, either as secondary enrichment ores or ores of possible primary origin. In the weathered zone of copper deposits a wide variety of oxides, carbonates, phosphates, arsenates, antimonates, sulphates, and vanadates occur. In the descriptions given herewith, the physical properties are mentioned in the following order: composition, crystallization, luster, streak, color, opacity, fracture, density, hardness, and specific gravity. The data for these descriptions come from Dana's "System of Mineralogy," and in some cases from Moses and Parsons' text-book. The specific gravity is given, as it is often convenient to calculate the number of cubic feet to the ton, which may be readily done when the proportion of mineral present and its specific gravity are both known.

There are about fifteen copper-bearing minerals which are of industrial importance, namely:

Azurite, bornite, chalcocite, chalcanthite, chalcopyrite, covellite, chrysocolla, cuprite, enargite, famatinite, malachite, pyrite, tenorite, and tetrahedrite. These important ore-bearing minerals, together with others of less importance economically, are those most frequently encountered in mining operations.

Native or Metallic Copper. — Native or metallic copper (Cu) is a dull-surfaced, characteristically copper-red mineral, having a metallic luster. It is the main ore mineral of the Lake Superior region, where it occurs both in small grains and in films disseminated through the rocks and in very large masses of many tons' weight.

Native copper is also found in the surface ores of very nearly all the great deposits of the continent, occurring mingled with the oxides and carbonates. In these latter cases it is a product of the weathering and decomposition of sulphide ores and is merely a surface phenomenon. It commonly occurs in irregular sheet-like masses, so coated with the white clays resulting from complete alteration of the inclosing rock that its nature is not apparent at first glance. In Bolivia such sheets are called *charco* (dried meat). It does not usually extend far below the outer weathered crust of the deposit, and is not commonly an important ore. In the basic rocks, notably the schists and gneisses of the Appalachian region, it is of common occurrence in masses, often several pounds in weight, which show on the surface of the ledge outcrops; and it was from such places that the Indians obtained their supply before the advent of the white man. In these deposits native copper occurs intimately associated with quartz, calcite, and epidote, as it does at Lake Superior. It often occurs inclosed in transparent quartz, and at the last-mentioned locality is sometimes well crystallized. It is sometimes formed indirectly as a replacement of the feldspar of igenous rocks, as shown in Fig. 7.

FIG. 7.—NATIVE COPPER, REPLACING FELDSPAR IN TRIASSIC ANDESITE-BASALT. COPPER UNION, COPPER BUTTE DISTRICT. *f*, FELDSPAR; *c*, CHLO-RITE; *cp*, COPPER. (MAGNIFIED 120 DIAMETERS. LINDGREN)

Azurite $(CuCO_3)_2$, $Cu(OH_2)$, or chessylite, blue carbonate of copper (61 per cent copper), is a brittle, opaque mineral, with a vitreous lust[illegible] a blue streak, and a color which varies from a ligh[illegible] to a d[illegible] rich blue. Hardness, 3.5 to 4.5; specific gravity, [illegible] It occ[illegible] in crystals and as massive incrustations on oth[illegible] and crevices; it is also dull and earthy. When crystallized it is partially translucent. It is common in radial nodules in the altered rocks of ore deposits. As an ore it requires only a passing notice, as with the exception of the deposits at Bisbee and Clifton, Ariz., it does not occur in any quantity.

Bornite (Cu_3FeS_3), known variously as erubescite, purple, variegated, peacock, or horse-flesh copper, is a mineral with a superb metallic luster, whose color varies from copper-red to pinchbeck-brown, but which tarnishes easily to every conceivable hue of red, blue, and purple. It occurs in massive bodies with either a granular or compact structure, and is brittle. Its approximate composition is: copper, 55.58 per cent; iron, 16.36 per cent; sulphur, 28.6 per cent. Luster, metallic; grayish black streak. Opaque and brittle, with traces of octahedral cleavage. Hardness, 3; specific gravity, 5.

Bornite, though sometimes found in the outcrop of copper deposits as a reduction produced by organic matter, is more commonly found under conditions similar to those of glance; that is, as a characteristic ore of secondary enrichment deposits. In some veins, notably the Original mine at Butte, Mont., it occurs under conditions indicating primary deposition, and it has been faulted, crushed, and recemented by later ores. In many contact metamorphic deposits it is certainly primary.

This is an important ore of copper in many mines, notably in some of the mines at Butte, Mont., in Chile, South Africa, Tasmania, and a few Australian mines. Its mode of occurrence and the fact that in most mines it is abundant in the upper part of the vein, but disappears in depth, mark it, like copper glance, as a product of decomposition, solution, and redeposition of the metallic portion of the vein. It occurs associated with pyrite, quartz, and sometimes with calcite or other earthy carbonates. It changes on weathering to iron oxide and glance, which commonly changes further to copper oxide and carbonate.

Bournonite occurs in cog-wheel aggregates of modified rectangular prisms. Composition: copper, 13 per cent; lead, 42.24 per cent; antimony, 25 per cent; sulphur, 29.6 per cent. Hardness only 2.5 to 3; specific gravity, 5.766. It is found in various mines of central Europe and Siberia.

Chalcocite, or copper glance (Cu_2S) (79.8 per cent copper), sometimes called vitreous copper, is a dark, lead-gray mineral, often tarnishing to blue or green. It has a lead-gray streak, a metallic luster, and, while sometimes found in crystals, usually occurs in massive form as black, granular or compact masses with metallic luster, or in nodules or replacements of fossil wood. It is sometimes soft and malleable, forming a lead-like streak when struck by the point of a pick, and is thus readily recognized underground even when mixed with other minerals. Hardness, 2.5 to 3; specific gravity, 5.5 to 5.8.

Chalcocite is the most important ore of the metal in the copper deposits of America. It is the chief ore mineral of Butte, Cananea, and many of the Arizona mines. In the Butte ores it occurs in great masses of nearly solid mineral 20 ft. across, and has in the upper parts of the deposit the dull fracture of lead. It is, however, generally crystalline either with the grain of steel (Butte) or a coarser lamellar fracture (Arizona and Virginia). This mineral is undoubtedly primary in some deposits, but is more often of secondary origin and formed by the partial oxidation of primary deposits of cupriferous pyrite and chalcopyrite, whose copper was carried downward by surface waters and precipitated either above or below water level, but beneath the zone of free oxygen. In most mines it occurs very commonly as a black, sooty ore, often of a loose, almost ashy texture, found beneath the leached and barren "iron hat" (limonite) that forms the outcrop and upper part of the vein, and the underlying sulphide ore that is usually encountered at water level. The ore does not usually extend far below the water level; but the mines at Butte, Mont., are a remarkable exception to the rule, as there it occurs in large quantities in the deepest levels, 2400 ft. or more. Chalcocite is generally associated with pyrite and chalcopyrite, and it alters to cuprite and malachite. The mineral often carries admixed iron oxide as an impurity.[1]

Chalcanthite ($CuSO_4.5\ H_2O$), blue vitriol, or bluestone, is a sulphate of copper. It is a brittle, subtranslucent mineral, with a vitreous luster and a peculiar disagreeable metallic taste. It occurs in crystallized form, and as incrustations of fibrous, botryoid, or stalactitic form, and usually ranges in color from sky to dark blue, though sometimes it has a greenish blue color. It has 25.4 per cent copper, and is soluble in water. It is a decomposition product, resulting from the oxidation of copper sulphides, and is carried in solution in mine water. It was found in quantity at the Bluestone mine near Reno, Nev., from which locality large shipments were at one time made, and at Copiapo, Chile. It occurs in stalactites in many of the Butte, Mont., mines, which oftentimes extend from roof to floor and all but completely close old passages. When mine waters contain large amounts of this mineral, the copper is very

[1] Brush-Penfield, "Determinative Mineralogy."

successfully extracted by precipitation by scrap iron, as in Ireland, Rio Tinto, and Butte, Mont.

Chalcopyrite, or copper pyrite ($CuFeS_2$), is a brass-yellow ore of copper with a high metallic luster, which is subject to tarnish, and often presents a beautifully iridescent appearance. The intensity of the yellow color varies inversely with the amount of iron pyrite mixed with it. When pure it contains 34.5 per cent copper, 30.5 per cent iron, and 25 per cent sulphur. It is usually massive; is distinguished from pyrite by its softness, 3.5 to 4; and is of a darker color. This is the most common copper mineral of the ore deposits of the world, and though not the prevailing mineral in the greatest producing mines of the United States, it is of widespread occurrence and is the source of the copper of the Appalachian producers as well as of most of the European deposits.

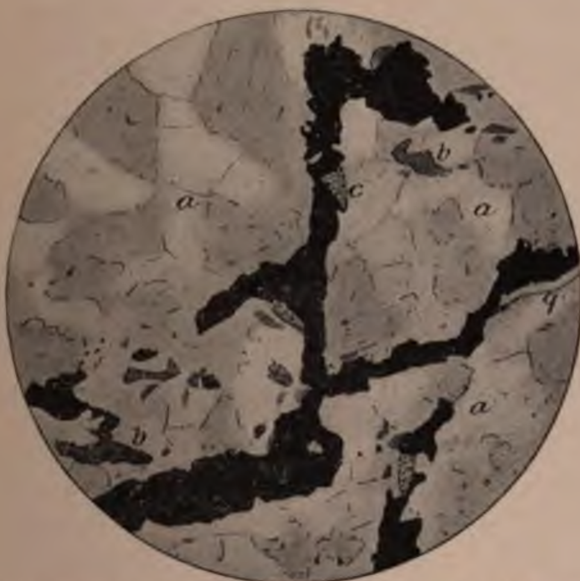


FIG. 8.—REPLACEMENT VEIN IN SYENITE ROCK. WAR EAGLE MINE, ROSSLAND, B.C. *a*, GRANULAR AGGREGATE OF ORTHOCLASE WITH VERY LITTLE SERICITE; BLACK, SECONDARY PYRRHOTITE; *b*, SECONDARY BIOTITE; *q*, SECONDARY QUARTZ; *c*, CHLORITE. (MAGNIFIED 60 DIAMETERS)

It is often regarded as the "mother" copper mineral; and it and cupriferous pyrite are original sources of various other copper minerals the world over. It occurs massive in pyrrhotitic and pyritic ores, in veinlets, patches, and knots. In many gold veins it is highly auriferous. It occurs in the replacement veins of Rossland, B.C., but is not a common product of ordinary hydrothermal metasomatic replacement. It is common in contact zones. "It forms irregular masses, is rarely crystallized, and in replacements is frequently accompanied by a narrow lining of chlorite.[1] It is easily decomposed on weathering, and hence forms from its contained iron the gossan or "iron hat" of the lodes.

Chalcopyrite often occurs in pyrrhotite under the same conditions as in pyrite, and rarely, as at Wright and Osborn's mine at Blayney, N.S.W.,[2] there is a transition from the gossan of magnetite and hematite through pyrrhotite to pyrite with chalcopyrite, due to the gradual elimination of the sulphur, the extra atom of which is first removed from the pyrite (FeSS).

It is the main ore mineral of the mines of Bingham, Utah; Ducktown, Tenn.; Shasta county, Cal.; United Verde; Rio Tinto; Japan; and Tasmania; in fact, of many of the great mines of the world.

Chalcopyrite is, with cupriferous pyrite, the universal primary ore of copper deposits. It is found as a primary original constituent of igneous rocks, both acid and basic, and segregated it sometimes forms with pyrite workable deposits in the basic rocks. It is also the chief copper mineral of contact metamorphic deposits, of complex copper-zinc-lead ores, and is found in many gold veins. It is the great universal copper mineral the world over. Though undoubtedly primary in many ores, yet it is also found as a secondary ore in many mines, and oftentimes an ore will contain both primary and secondary chalcopyrite. At Butte, Mont., in the copper veins, primary chalcopyrite has not been found, but the mineral, though not abundant, is not rare in secondary veins in the copper area, and it is common in the silver veins proper.

Covellite (CuS) (66.5 per cent copper). — This blue material, in many respects the most beautiful of all copper minerals, is rare as an ore, being produced in large quantities from but one mine, the Grayrock, of Butte, Mont. It consists of cupric sulphide (CuS), is a bright and vivid blue, and occurs associated with much kaolin as an alteration product of undoubted secondary origin, derived in part from cupriferous pyrite under conditions of incomplete oxidation. It is often a dull blue-black mineral in seams and accompanied by an earthy matrix. It is found near Grand Encampment, Wyo., as an ore.

[1] W. Lindgren, "Metasomatic Processes in Fissure Veins." *Transactions* American Institute of Mining Engineers, vol. xxx, p. 578.

[2] Carne, *op. cit.*, p. 18.

Chrysocolla ($CuSiO_3 + 2\ H_2O$). —This beautiful bright green copper silicate has an opal-like or enamel-like texture. It is common in crusts and masses about many copper deposits, particularly in silicious and in igneous rocks. It is a product of decomposition, and seldom occurs in large quantity, the exceptional cases being in Arizona and Texas, where extensive areas are underlaid by it. The ore will be valuable, if it can be cheaply treated by leaching processes. It varies in color from green and bluish green to turquoise blue, and, if impure, to brown or black. It is easily scratched by the knife, and has a white streak. It contains 45.2 per cent copper oxide, the equivalent of 36.06 per cent copper, 34.3 per cent silica, and 20.5 per cent water. It is an alteration product.

Cuprite (Cu_2O), or red oxide of copper (88.8 per cent copper), usually occurs in some shade of red or brown, often cochineal red by transmitted light. Occasionally it is iron gray on the surface, but it always gives its characteristic red streak. It has a luster varying from adamantine to submetallic or earthy, and is quite brittle. Hardness, 3.5 to 4; specific gravity, 5.85. It is always found in the weathered portions of copper deposits, but seldom in large amounts. Nowhere is it mined alone, as it always occurs mixed with the carbonates, malachite and azurite, in the ores. In these weathered ores it is an important constituent. It is common in the Appalachian deposits and in Arizona. Mixed with hematite or limonite it forms the "tile" ore of some of the New Mexico deposits. It is, however, only important as an ore in the early development of the deposits. It commonly forms from the oxidation of sulphides, but is also known to form from native copper.

Enargite ($3\ Cu_2S \cdot 2\ As_2S_3$), sulpharsenide of copper, contains 48 per cent of copper. This ore is relatively rare, and until lately has not been of commercial importance. In the past few years the mines of Butte, Mont., have developed remarkably large deposits of this ore until now it nearly equals copper glance in amount. It is an iron-black to gray-black, brittle, opaque mineral that rarely occurs in crystalline form, but is commonly massively crystalline, with well-defined cleavage and bright luster. Underground in candle-light it closely resembles sphalerite. The presence of 19 per cent of arsenic in a copper ore was formerly held to result in the production of a very inferior copper, but with the present practice of electrolytic refining this c[illegible] removed. The ore is characteristic [illegible] zones [illegible] and Chilean deposits, and is [illegible] h. At Butte it is a deep-se[illegible]

Enargite has usually been regarded as a secondary ore, and does not extend to very great depths in most of the South American mines. Its occurrence at Butte is, however, opposed to this, as in some veins it occurs below the glance zone and at depths of 2000 ft. or more. It is a common but not abundant ore mineral in South American mines and in the island of Luzon, Philippines, and the Tintic district of Utah.

Famatinite ($3\ Cu_2S \cdot Sb_2S_5$). — Isomorphous with enargite. A gray, tinged with copper-red, mineral. Specific gravity, 4.57. From Famatina district, Argentina, and many copper mines of the Andean region.

Malachite ($CuCO_3 + CuOH_2$) (62 per cent copper) is a bright green carbonate of copper, occurring usually massive or concretionary, less commonly in crystalline or fibrous forms. The crystal forms have a brilliant luster, inclining to vitreous, while the fibrous varieties have a silky appearance, or are dull and earthy. The massive forms may be massively crystalline or have a dull and earthy fracture. This is much the most important oxidized ore of copper, and in the Russian (Ural) mines it occurs in large and solid masses, from which various vases and other works of art have been cut. It is widely distributed, occurring ordinarily in non-paying quantities. In the gossan region of various deposits, there are certain localities where it forms the principal ore of the metal, being characteristic of the upper or decomposed parts of most copper deposits, especially where the country rock is limestone. It rarely occurs pure, but is mixed with clays, iron, and manganese oxides, and quartz, chalcedony, etc. Owing to its brilliant green color a very small amount will stain a very large amount of rock or vein matter, or color thin and worthless incrustations, or nodules of valueless material, so that it is difficult and, in fact, often impossible, to form any accurate opinion of the ore from its external appearance. It occurs associated with cuprite, and less commonly with small amounts of azurite, at almost every known copper deposit.

Malachite is formed by the action of acid waters coming from decomposing sulphides, in contact with limestone or other carbonates, and hence is less abundant in veins in granitic rocks (Kemp). It is also formed by carbonated surface waters acting on other copper minerals forming pseudomorphs after cuprite and azurite. When in a pure sandstone or silicious or other insoluble matrix a very low-grade ore can be treated at a profit by leaching, as in Perm, Russia.

Olivenite ($Cu_4O_9As_2$), hydrous copper arsenate, containing 56.15 CuO, is an olive-green to liver- or wood-brown mineral, subtransparent to opaque, and brittle, that occurs in fibrous and granular massive forms in the oxidized zone of copper deposits. It is the commonest of a list of eight or nine copper arsenate minerals.

Pisanite is a mineral composed of copper sulphate and iron sulphate; it is usually regarded as impure bluestone.

Pyrite. — Copper-bearing deposits of pyrite are common the world over. Such ores usually show chalcopyrite mixed with pyrite in patches, veinlets, spots, etc., and glance often occurs in this way. The rich Huelva ores are familiar examples. There is no doubt, however, that pure pyrite, so far as crystallographic and microscopic tests can determine, carries a small amount of copper; and the precise nature of this copper content is not known. It is commonly assumed to be present as minute particles of copper pyrite; but mineralogists are not agreed whether the chalcopyrite molecule replaces part of the pyrite chemically or whether it is merely present as a physical mixture. The study of thin sections of ores from the Huelva field, California, Butte, and Tasmania, shows a mechanical mixture; and this is the more probable occurrence.

FIG. 9.—CRYSTALS OF PYRITE FORMING BY REPLACEMENT IN CHLORITIC DIABASE ALONG CRACKS FILLED WITH CALCITE. GREAT NORTHERN MINE CANYON, IDAHO p = PYRITE; BLACK = CALCITE; SHADED = CHLORITE. (MAGNIFIED 12 DIAMETERS. LINDGREN)

Pyrite is the most common sulphide formed by metasomatic processes. It impregnates the vein wall rocks, and has a remarkable tendency to crystallization when formed in this way, as contrasted with its often massive texture when it occurs as a cavity filling.

Cupriferous pyrite presents the same variations and texture as the barren variety.

Rickardite (Cu_2Te), telluride of copper, is a brilliant purple mineral found as a rarity at Cripple Creek.

Tennantite ($Cu_8As_2S_7$), a compound of copper, iron, and arsenic, allied to enargite, and grading into tetrahedrite by replacement of the arsenic by antimony, is a dark, lead-gray or black metallic mineral, with red-gray streak. It occurs in brilliant isometric crystals and as a massive ore, in Utah. It is opaque, has metallic luster, and a hardness of 3.5 to 4. Specific gravity, 4.37 to 4.53.

Tenorite (melaconite) (CuO), the black oxide of copper (79.85 per cent copper), occurs either massive or as a dull black earthy powder (melaconite). The pure mineral is compact, has metallic luster, and is a steel or iron-gray color when in thin scales, but when massive it has a jet black glassy or grayish black color, or is dull and earthy, and soils the fingers in handling it. It is not an important ore, for most of the so-called black oxide ores of the mines are really earthy glance. It occurs in iron-gray flexible scales in Vesuvian lavas (Dana), and in dull black masses and botryoidal concretions in many deposits.

Tetrahedrite (essentially $Cu_8Sb_2S_7$), or gray copper, or fahlore, is an opaque, rather brittle mineral, with a metallic luster, whose color varies from light steel-gray to iron-black. It is a complex ore, iron, zinc, lead, mercury, and silver often replacing a part of the copper. A fair estimate of its composition would be: copper, 30 to 40 per cent; antimony, 15 to 25 per cent; sulphur, 20 to 25 per cent. Hardness, 3 to 4.5; specific gravity, 4.5 to 5.1. It is not an important ore of copper, as it seldom occurs in large quantity. The silver-bearing varieties are mined not so much for the copper as for the silver content. Only the most favorable circumstances — mineralogical, metallurgical, and commercial — would render the working of non-argentiferous fahlores at all practicable (Peters). The improved methods of recent years make a modification of this statement necessary; for the obnoxious components (arsenic, antimony, etc.) are no longer a metallurgical bugbear. Where it can be mixed with other ores there is no trouble in treatment. It is its scarcity rather than its character that makes it relatively unimportant. It occurs outside the copper belt at Butte, associated with chalcopyrite, and in Mexico, Bolivia, Chile, and many European mines.

Tetrahedrite occurs as an undoubted redeposited or secondary ore in many deposits, and so far as known does not occur in any abundance in the deeper parts of copper mines. Its presence, however, at considerable depths in the Cripple Creek mines, at Butte, Mont. (1200 ft.), and a few other localities, indicates that it is at times a primary mineral.

The following minerals embrace the less common sulphantimonites and arsenites of copper: chalcostibite, emplectite, binnite, stylotypite, aikenite, polybasite.

The copper arsenides include: domeykite (Cu_3As), mohawkite, algodonite (Cu_6As), whitneyite (Cu_6As). They form a basic series whose increment is Cu_3, corresponding to similar silver compounds.

Three selenides are of not uncommon occurrence: berzelianite, eucairite, crookesite.

Only one copper telluride, namely, rickardite, has thus far been recognized.

The list of sulphates is quite large, the following being the more common species: brochantite, krisuvigite, königite, langite, cyanotrichite, kröhnkite, antlerite, linarite, dolerophanite, hydrocyanite, connellite.

The phosphates of copper include a number of species, of which the more important are the following:

Pseudomalachite (phosphochalcite, ehlite, dihydrite) occurs in oblique crystals, or massive and incrusting, and has an emerald or blackish green color. Hardness, 4.5 to 5; specific gravity, 4.34; contains 64 to 70 per cent of copper oxide. From near Bonn, on the Rhine, and also from Hungary.

Libethenite has a dark or olive-green color, and occurs in crystals, usually octahedral in aspect, and massive. Hardness, 4; specific gravity, 3.6 to 3.8; contains 66.5 per cent of oxide of copper. From Hungary and Cornwall, and rare at Morenci.

Other copper phosphates are *veszelyite, tagilite, isoclasite. Torbernite* is a copper-and-uranium phosphate. These phosphates give no fumes before the blowpipe, and have the reaction of phosphoric acid.

Three copper vanadates occur; viz.: *volborthite*; a copper-and-uranium vanadate from the Urals, and *mottramite* and *psittacinite*, copper-and-lead vanadates, the former from England, and the latter from gold mines in the Silver Star district, Madison county, Mont.

Associated Gangue Minerals

The commonest gangue mineral of copper ores is quartz, which occurs in a variety of forms, but usually is clear and glassy and finely to coarsely crystallized. Calcite, the carbonate of lime, and siderite, carbonate of iron, are common in some deposits, but in only a few of the great mines of the world. Barite is an exceptional gangue, found in abundance in the Shasta county (Cal.) ores, in those of Mount Sicker on Vancouver Island, B.C., and also at Kosaka, Japan, and at Mount Lyell, Tasmania. Rhodochrosite and fluorite also occur, the latter especially in the tin and copper mines of Cornwall, England, and rarely at Butte, Mont.

Very often the copper ores occur with an earthy gangue composed of highly altered country rock. In the great mines of Montana, Japan, Tasmania, and other countries, the alteration has resulted in the formation of sericite, a form of muscovite, in extremely minute microscopic scales. The nature of the gangue minerals and of the rock alteration is important, as from it can be correctly inferred the character of the vein-forming solutions. As discussed in the chapter on "Genesis of Copper Deposits," there is some evidence that a solution coming up through a fissure will alter the vein walls, forming sericite, while the same solutions percolating further inward, after reacting with the wall rock, have a somewhat different composition and produce different effects on the country rock remote from the vein walls.

FIG. 10.—TOURMALINE ORE, COPPEROPOLIS, QUARTZBURG DISTRICT, OREGON. (BLUE MOUNTAINS OF OREGON. WALDEMAR LINDGREN)[1]

Tourmaline. — "This very complex silicate of aluminum, magnesium, ferric iron, and sodium contains about 10 per cent of boric acid, a little combined water, and some fluorine. In metasomatic development, it forms irregularly massed crystals, or single crystals impregnating the mother mineral. Its tendency to crystallization is very strongly marked. It replaces orthoclase and plagioclase, as well as quartz, but is not known to be formed from ferromagnesian minerals.

[1] Twenty-second Ann. *Report* of Geological Survey, part ii, plate lxx.

Small almost perfect crystals may develop in the feldspathic substance, without disturbing its optical orientations. Tourmaline may also form in fine-grained clastic rocks like slate. The only occurring variety is black, usually showing dark brown and dirty bluish or greenish colors in thin section. Tourmaline often occurs in large masses of small felted individuals, together with quartz, entirely replacing the original rock."[1] The mineral is confined to tin-copper veins and to the allied group of the gold-copper-tourmaline veins.

Deleterious Minerals in Copper Ores

Copper ores often contain metallic minerals, which cause trouble in the reduction of the ores. The most obnoxious of these minerals is probably zinc, usually present as sphalerite. This mineral is so troublesome in ordinary copper smelting that usually each percentage in excess of 10 per cent is charged for at the rate of 25 c. per unit, being known as the "zinc penalty."

Bismuth, usually present as bismuthinite, is also extremely objectionable, but is, fortunately, comparatively rare. It is quite troublesome in some Australian ores; but since the general introduction of electrolytic refining it has ceased to be the bugbear that it once was.

The last remark applies also to arsenic and antimony, the former, in the shape of arsenopyrite or mispickel, being a common and very objectionable associate of copper ores. While arsenic, antimony, tellurium, and selenium are partially eliminated in modern smelting methods, it is only since the introduction of electrolytic refining that the resulting copper is pure enough for electrical uses.

[1] W. Lindgren, "Metasomatic Processes." *Trans.* Am. Inst. Min. Eng., vol. xxx, p. 613.

IV

GEOLOGIC DISTRIBUTION AND OCCURRENCE

Distribution

The geologic distribution of copper is a matter of much importance to the mining industry; for wide distribution does not mean abundance.

A consideration of all the known facts of geologic distribution leads to the following general conclusions: (1) The workable copper deposits of the world are, with a few noteworthy exceptions, coextensive with areas of igneous rocks, usually intrusive, or with areas of the metamorphic derivatives of such rocks. (2) There is a world-wide association of copper ores with Red Beds of Permian and Triassic age. (3) Deposits are found in many areas of crystalline schists, which, though similar in texture and composition, are of different ages; the rocks may be igneous, altered sediments or metamorphosed contact facies of sediments.

Igneous Areas.—That copper deposits occur with igneous rocks is a well-known fact; but the converse is not true, and areas of igneous rocks are neither invariably nor commonly ore-bearing. The recent lava flows, basalts and rhyolites, and the associated fragmental volcanic rocks seldom contain valuable copper deposits. The genetic relation of copper ores and igneous rocks is fully discussed in another place; but it is significant to note that copper deposits cluster about the borders of great bodies of granitoid rocks, as, for example, those along the west flanks of the Sierra Nevada range of California, or the smaller batholiths of the Banat range of Hungary, and the igneous cores of numerous small and isolated ranges in the copper districts of New Mexico, Arizona, and Sonora. Areas of limestone, altered to garnetiferous and lime-iron silicate rocks, are frequently copper-bearing, even though an igneous core is not exposed, as in the Urals. More often the altered porphyry or granitic rock adjacent to such contact rocks yields the best returns.

Areas of old and schistose as well as recent and recognizably igneous rocks contain copper deposits. The Norwegian copper districts are familiar examples of this kind.

Batholithic margins rather than centers are favorable. Though it is true that relatively few areas of intrusive igneous rocks show copper deposits, it is a well-established fact that even in a developed copper district the areas devoid of intrusive rocks are barren, the deposits occurring in the igneous rocks or close to the contact. This association is so significant and important that it will be repeatedly emphasized in this work.

Permian (and Triassic) Areas.—It is a singular fact that certain thin but well-defined beds of the Permian (and Triassic) Red Beds of each of the continents contain copper ores. The number of localities where the ores occur in workable amount is few, but ores are found at many places. The red rocks are the most conspicuous beds at most of the localities, though gray and green sandstones and shales occur in equal abundance. The copper ores are usually found in gray patches in the red rocks or in the gray beds. The Red Bed rocks are peculiar, and record exceptional conditions of climate and sedimentation, with continental uplift, mountain growth, igneous activity, and concentration of salt water to gypsum and salt in inclosed basins.

Deposits of this age occur in many parts of the eastern or Ural governments of Russia, in northeastern Bohemia, in the Mansfeld basin of Germany, at Coro Coro, Bolivia, Camaquam, Brazil (Rio Grande del Sur), and in the Katanga province of the Congo Free State, while the similar beds of the Trias of Alsace-Lorraine, and the Cretaceous at Coyame, Chihuahua, Mexico, also carry copper ores.

In the United States such deposits occur in many and widely separated localities, but, of course, only at certain places and not universally in the rocks of each district. The Red Beds of the Atlantic border (the Newark formation) contain small amounts of copper in Nova Scotia, and in a number of localities in New Jersey and Virginia, often alongside of diabase intrusions.[1] The occurrence of such ores in the Trias of the Western States has been described repeatedly with a fullness not warranted by the slight economic importance of the deposits. The literature [illegible] deposits contains frequent references to the ores of Nacimiento, [illegible] of the Brazos and Red river valleys of Texas, and of the [illegible] isolated mountain ranges lying in New Mexico north of

[1] [illegible] rsey." *Report* State Geological Survey, 1903.

El Paso, Tex., while Emmons has recently described those of the Uncompahgre plateau and the Grand Canyon districts.[1]

In the crystalline schists the deposits are mainly of the so-called Huelva type, but are as varied in their geologic relations as those found in igneous areas. The deposits of crystalline areas are alike in form and superficial character, and so are the rocks; like the latter, the deposits differ in composition, age, and origin. There is thus a general correspondence, due to metamorphic and structural conditions. The character of this type is discussed in the chapter on "Classification of Copper Deposits." It is sufficient to say here that the deposits are often associated with sheared igneous rocks, and in the biotite- and quartz-schists (altered sediments) that they are often found in the roots of deeply eroded and planed down mountain ranges, as, for example, in central and northern Norway, at Ducktown, Tenn., and Besshi, Japan. The deposits of this type include many of the mines of Europe, Japan, Mexico, and the United States.

Oftentimes the only copper-bearing member of a schist is a band of amphibolite, usually an altered diabase.

Age of Deposits. — Lindgren has shown[2] that in the western United States the deposition of gold ores corresponds to periods of igneous activity; that certain periods of ore deposition stand out prominently and afford good reasons for distinguishing "the distinctly Cretaceous or late Mesozoic gold belt of the Sierra Nevada and the Pacific coast in general from the Tertiary, mostly post-Miocene veins, so extensively developed in Mexico, Nevada, and Colorado," his conclusions being that the former are genetically connected with great intrusions of granitic and dioritic rocks, the latter with big flows of surface lavas which erosion has not as yet removed. This holds true in a general way for copper deposits as well, though copper deposits are more closely connected with intrusive bodies of granitic rocks of post-Cretaceous age, exposed by active erosion, than with surface rocks.

Copper deposits occur in rocks of all ages, though the deposits themselves are in large part post-Cretaceous. The same genetic dependence upon periods of igneous activity is shown by the [illegible] silver deposits.

Copper deposits have been formed in various [illegible] periods. The

[1] S. F. Emmons, "Copper and Red Beds of the Colora[illegible] Bull[illegible] United States Geological Survey, p.

[2] "Geological Features of the G[illegible] of the American Institute of Mining Eng[illegible]

Algonkian and early Cambrian rocks contain ore deposits associated with disguised volcanic rocks now represented by pearly sericitic (so-called talcose) schists, and in a few instances the deposits occur in sediments now altered to biotite- and quartz-schists, as, for example, the Ducktown, Tenn., deposits. Later Cambrian and Silurian rocks are only known to carry copper as introduced material, and ore deposits of this age are not known. Devonian and Carboniferous rocks contain copper deposits, but they are of later age. Those formed during Carboniferous time are of small extent and low-grade character, and no workable deposits of these periods are known. In the United States, at any rate, the Paleozoic sedimentary record shows an absence of notable dynamic movements and of relatively slight igneous activity. The Permian deposits have already been noted.

For America three great periods stand out; namely, the pre-Cambrian, the Triassic, and the Tertiary. The last is by far the most important in both North and South America, also in Japan. The exact age of the Huelva deposits is not settled, but it is certainly post-Carboniferous. The Mansfeld deposit is either Permian or Triassic. The Permo-Triassic rocks are copper-bearing the world over, though seldom workable. The age of many deposits is so uncertain that no further deductions can be safely drawn.

With the beginning of the Tertiary period an epoch of igneous activity was ushered in in America that has continued, with occasional interruption, from that time to the present; and the rocks are accompanied by workable copper deposits at a number of localities. In the Rocky Mountain region of Montana and Colorado there is some evidence of igneous activity in late Jurassic and Cretaceous time; but the really great period of uplift and of igneous activity began in post-Cretaceous time, and entirely altered and effaced the former character of the country.

It must be remembered, however, that reopening of veins and superimposition of ores of two or several epochs have certainly taken place in some deposits (Butte) and tend to complicate the problem of a correct division of the deposits according to age.

Association with Mountain Ranges. — Copper deposits are characteristically confined to mountain regions, either the great ranges of today, or old and planed-down ranges whose stumps alone remain. As a rule, the earth crumpling that formed the ranges was accompanied by volcanic activity, and the copper ores are found in the areas of igneous, mainly intrusive rocks.

[illegible]wing the location of the world's greatest mines does not bring out this association so well as if all the known deposits of the metal had been shown.

This influence of mountain building is not confined to the immediate mountain region. The Red Beds (Permian) on the west flank of the Urals in Perm, Russia, show a gradually lessening copper content for three hundred miles outward from the mountains.

In general, the text-books advise looking for deposits in regions of rounded, gentle mountains, areas of topographic maturity or old age, rather than in young and youthful mountains. This is, however, not a safe rule to follow in North and South America. The great deposits of western America do not occur under these conditions, though most of the European deposits do so occur. In general, the known copper deposits of the world show a marked occurrence along areas of mountain uplift and corrugation, usually coinciding with areas of active volcanism, either old or recent.

Mineralogic Provinces. — The copper deposits of a district commonly show strong family resemblances, the deposits as a whole possessing peculiarities distinguishing them from those of other regions, even though the individual deposits of this district may be quite varied. This resemblance may be shown in the mineralogic development, association, or texture of the ore and gangue minerals; also in structural relations. Thus, the deposits of Butte, Lake Superior, Catini (Italy), Kedabeg (Russia), Huelva (Spain), in fact, most of the great copper districts of the world, are quite unlike in their general features, while the individual deposits of each place show a strong likeness to each other. This is true even though the type of the deposit be the same in two districts, as, for example, at Morenci, Ariz., and Ely, Nev. In a broader way the deposits of a region may show resemblances akin to those of races in mankind. These broader features coincide more or less with petrographic provinces, areas in which the igneous rocks show common characteristics or kinship.

Occurrence

Copper ores occur in deposits of various forms as well as in varied rocks. The so-called bedded veins in crystalline schists, whether of Archean or later age, form lenticular orebodies the world over. Even in schists that are sheared igneous rocks of late geologic age the form is the same, being usually a long and more or less regular lens, while in depth they vary in shape, and often have the flat-rounded cross section of a boat with or without a keel. These lenticular bodies often overlap and are sometimes due to flat faults displacing a once continuous pipe of ore. The Mount Lyell deposit, Besshi (Japan), and the Huelva deposits are familiar examples, the first showing proved faulting. There is no distinction to be made, except in copper contents, between these deposits and those of pyrite mined as a sulphur ore.

This mode of occurrence, though apparently simple and alike the world over, shows wide differences in various districts. The lenses of Nababeep are an unusual type, showing lenticles. There is a tendency toward a lenticular type in contact metamorphic deposits.

A majority of the workable copper deposits of the world are veins, usually cutting igneous rocks. Such occurrences show all the varied physical and mineralogic characters of mineral veins of the various types, filled fissures, fissures with impregnated walls, replacement veins, etc. Such structural features are fully discussed in text-books on ore deposits.[1] The ore may occur in well-defined and limited shoots, as is common, or as simple and regular vein filling. There is apparently no relation between the occurrence of the ore in veins and its mineralogic character. The veins may occur in any rock; they are most frequently profitable in igneous rocks.

The term "vein" is often erroneously applied to the bedded deposits of Lake Superior and to the impregnated beds of tilted sandstone of Bolivia, Brazil, and Africa.

The occurrence of copper ores in extremely basic rocks is commonly in stock-like bodies. At Sudbury and in the magmatic segregations of Norway and Italy the ore forms lenticular bodies and arms lying along the border of the mother rock.

The extreme diversity of occurrence, even when the deposits are due to one series of ore-depositing factors, is particularly well shown at Morenci, Ariz., where Lindgren has distinguished the following varieties, based upon occurrence and form:

Deposits in limestone and shale, not connected with fissure veins (all carry oxidized ores almost exclusively; rarely chalcocite):
- Irregular bodies near contacts of main stock or dikes.
- Tabular bodies near contacts of main stock or dikes following stratification.
- Tabular bodies following contacts of porphyry dike.

Fissure veins:
- Normal veins in porphyry or in any of the other rocks near porphyry contacts.

[1] See "The Nature of Ore Deposits," by R. Beck, translated by W. H. Weed.

The pay part includes both the central, sharply defined veins and the surrounding partly replaced porphyry, forming together a lode. They carry chalcocite as the important ore. In upper levels they sometimes carry oxidized ores also.

Normal veins following porphyry dikes in granite, and carrying chalcocite and oxidized copper ores.

Normal veins following diabase dikes. These carry chalcocite and oxidized copper ores.

Stockworks:

Irregular disseminations in porphyry, quartzite, and other rocks.

Contain chalcocite and oxidized copper ores.

This is the best description of the diverse occurrence of ores in and about an igneous intrusion that I have yet seen. It includes a greater variety than is commonly found, but expresses the notable fact that occurrence and form are dependent upon physical conditions.

Beds of copper ore occur in sedimentary rocks. Besides the cases just mentioned there are many others known. Such deposits may be flat, like the Mansfeld deposit, or so steeply tilted as to simulate a vein.

Copper ores form the so-called stocks in contact rocks. Such deposits are patchy and of uncertain extent and shape, though in tilted beds where one particular stratum is impregnated, and is inclosed by other impervious ones, the deposit is more reliable.

The great orebodies of Boundary Creek, Canada, and of Kosaka, Japan, are stock-like impregnations of tuffs; and Boleo is a mineralized bed of water-laid tuffs. The Sala deposits are impregnated beds of porous metamorphic rock.

The stocks of ore in altered serpentine rocks are irregular and costly to work. Catini is an example.

The great bodies of mineralized and altered, crackled porphyry, the "disseminated ores" of the western United States, are "stockworks" and occur only in igneous rocks. The tin-copper stockworks, a tangle of minute veinlets netting the rocks, are not always confined to the igneous rocks.

V

OUTCROPS AND GOSSAN FORMATION

ALL copper deposits alter by exposure to the atmosphere and the vicissitudes of climate. This alteration varies, but commonly results in a capping of leached and often worthless material resting upon a more or less altered part of the orebody. The effect of weathering, or, as it is technically called, superficial alteration, is to oxidize the ore; hence, if the primary ore contains much iron the outcrop is commonly a more or less impure brown hematite or limonite, whose texture and clinker-like aspect suggest to the untrained mind a volcanic origin. As such ironstone caps resist erosion well, they often stand out as walls or blocks above the surrounding slopes.

Many worthless veins show great gossan outcrops; and in moist countries the waters from decomposing sulphide ores flowing through the subsoil, or even on the surface, often form limonite masses which simulate gossan, but lie on the surface or extend but a few feet and irregularly downward.

The term "gossan" is commonly applied to the limonite masses that cap pyritic deposits, but is also used to designate the silicious, quartzy, or clayey residues left by the decomposition of the ore, and usually stained by iron, manganese, or by the green oxidized ores of copper. The great veins of Australia, of Butte, and of Morenci have no iron cap, but show inconspicuous, sometimes undiscernible, outcrops of rotted rock and quartz with no more copper "stain" than many worthless veins. As a rule, the more limonite the gossan shows the more iron sulphide there is in the fresh ore.

The width of the gossan is apt to be greater than the vein, as the down-seeping waters, carrying the products of the alteration of the ore, soak into the often altered and porous footwall rock and impregnate or even replace it with gossan material.

The depth of the gossan varies; if one includes the altered matter containing the oxide ores, it may extend down to the ground-water level.

This level is not that of the nearest stream channel, but that at which water would stand in a well in the spot, a level that follows more or less closely the contour of the land, but which in arid regions may be very deep.

Many copper deposits show a vertical distribution of material in belts or zones which may be distinguished as (1) zone of weathering, or surface zone; (2) zone of sulphide enrichment; (3) pyritic zone of lean primary ore.[1]

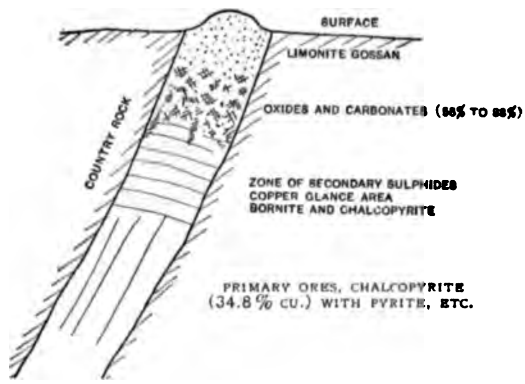


FIG. 11.—DIAGRAM SHOWING THE RELATION OF GOSSAN TO SULPHIDE ORES, ETC.

NOTE. In some regions a zone of argentiferous copper ores intervences between the carbonates and the secondary rich sulphides.

It is known that the ores of the upper two zones are derived from those of the pyritic or unaltered zone by direct or indirect oxidation. The zone of weathering shows the gossan outcrop and the underlying oxide ores. The zone of sulphide enrichment is characterized by copper glance as the most abundant mineral, but chalcopyrite, bornite, enargite, tetrahedrite, and rarely covellite are at times found in varying quanities. The zone of sulphide enrichment may lie above the ground-water level or below it.

The oxidation of a copper deposit of sulphide ores is practically the same whatever the form or character of the deposit. If the sulphide ore consist of pyrite or pyrrhotite with chalcopyrite, these minerals form sulphates. The pyrite in the ore changes by direct oxidation to ferrous sulphate and free sulphuric acid; the ferrous sulphate is further oxidized

[1] W. H. Weed, "Enrichment of Mineral Veins by Later Metallic Sulphides." *Bulletin* Geological Society of America, February, 1900.

to ferric sulphate, which in turn attacks the sulphides and changes them to sulphates, being itself reduced to ferrous sulphate, or is decomposed into basic sulphates, ferric hydrate, and free acid. These reactions form a cycle, with limonite as the final product of the outcrop if pyrite be abundant. The resulting ores contain ferrous and cupric sulphates and free sulphuric acid.

Oxide Zone

Beneath the gossan cap the lower part of the weathered zone often shows a wealth of the so-called oxidized ores of copper. These comprise carbonates, chlorides, bromides, silicates, oxides, and metallic copper, all formed from copper sulphate by the aid of the materials in the surface waters or by reaction with the earthy or limy material of the deposit or its walls. This is sometimes called the zone of oxide enrichment. There is a concretionary gathering of material to form nodules, crusts, or sheets, and the inclosing matter is usually leached and bleached and porous. Where the gangue consists of carbonates, their alteration and removal result in a marked loss in volume and consequent porosity.

The reactions by which the oxide ores are formed are many. The solutions consist of cupric sulphate, ferrous sulphate, and sulphuric acid. These can form cuprite as follows:

$$2\,CuSO_4 + 2\,FeS_2 + H_2O = Cu_2O + Fe_2(SO_4)_3 + H_2SO_4.$$

The acid reacts on the cuprite and forms native copper, as follows:

$$Cu_2O + H_2SO_4 = CuSO_4 + Cu + H_2O,$$
$$\text{or, } 3\,Cu_2O + 2\,FeSO_4 = 4\,Cu + Fe_2O_3 + 2\,CuSO_4.$$

The gangue minerals are also altered and affect the result. Silicious igneous rocks are attacked by the acids, and sulphates are formed. Carbonates disappear, garnet changes to limonite and quartz, and hematite and magnetite alter to limonite. If the ores undergoing oxidation contain copper glance, this mineral changes to cuprite and cupric sulphate, with covellite as an intermediate stage, and the cuprite is further altered by sulphuric acid to native copper.

In limestone the same solutions combine with calcium carbonate, and the chief reactions are between the lime carbonate and cupric sulphate, producing malachite, azurite, and gypsum, the last usually going off in solution. Ferrous sulphate will react with the lime and form limonite as an end product. Crusts of malachite formed in this manner often surround masses of limestone.

Another and important process is that due to a reaction between copper-sulphate solutions and shales, clays, or crushed rock. This is the probable origin of much of the chrysocolla found about copper deposits. All of these reactions depend upon direct oxidation and an abundance of oxygen. Lower down, where the free oxygen is exhausted, the sulphate solutions react with the primary pyrite ore and form secondary sulphides.

Secondary Sulphide Enrichment (Chalcocite Zone)

In many copper mines, notably at Butte, Morenci, Ely (in monzonite), and Ducktown in the United States, the gossan zone is almost devoid of copper. At Butte for 100 to 500 ft. below the surface the veins carried silver values but no payable copper ore, and were mostly devoid of even copper stain in some veins. Below this silicious silver ore — the gossan of the veins — immense bodies of very rich copper glance ore were found. At many mines similar ores are seen to lie between the gossan and the lean, unaltered, pyritic ores below. It is now definitely known that these rich ores are formed by the down-seeping, copper-holding waters reacting with the lean pyritic ores; and the usual limited downward extension of these rich ores is controlled by the depth to which this action has been possible.

The following equations indicate the chemical changes which take place when copper sulphates come into contact with pyrite:

$$3\,CuSO_4 + Fe_2S_3S = 3\,CuS + Fe_2(SO_4)_3 + S.$$

The ferric sulphate would be easily reduced by H_2S or S, the sulphur becoming free sulphur or sulphuric acid. The copper would be reduced from the diad to the monad condition by:

$$2\,CuSO_4 + H_2S = Cu_2S + S + H_2SO_4.$$

There are many changes possible: which would preponderate and what the final products would be where several are in simultaneous operation depend upon relative concentration, on temperature, and on pressure. One case, worked out with careful control of physical conditions by Stokes,[1] is as follows:

$$5\,FeS_2 + 14\,CuSO_4 + 12\,H_2O = 7\,Cu_2S + 5\,FeSO_4 + 9\,H_2SO_4 + 3\,H_2SO_4,$$

[1] H. N. Stokes, *Economic Geology*, vol. i, p. 644. See also Kemp same journal, vol. i, p. 11.

the last H_2SO_4 being formed by the oxidation of the sulphur of the pyrite. H. V. Winchell has produced chalcocite artificially by the action of pyrite on copper sulphate.[1]

The common mineral of orebodies formed of enriched sulphides is chalcocite. This is usually formed in the manner indicated in the preceding paragraphs, but in a minor degree is due also to a reaction with sphalerite as observed by Winchell at Butte and by Lindgren at Morenci. Covellite is common at Butte. Bornite, chalcopyrite, enargite, and famatinite are found as secondary ores in the upper parts of veins in Chile, and some of these minerals are found as secondary deposits elsewhere. The evidence for tetrahedrite, as for several of the arsenical ores, indicates that these minerals may be original but are often secondary. (See chapter on "Mineralogy of Copper.")

Figure 12 represents a thin section of ore (Bingham, Utah), showing replacement of pyrite by copper glance (secondary sulphide enrichment).

The formation of chalcocite from pyrite, the reactions of which have already been given, is the most important process of sulphide enrichment, as most of the rich orebodies, of America at least, are due to this action, and, according to C. H. Jones,[2] the Huelva ores carry their copper in this form. The process is one of direct replacement, both peripherally and along cracks and fractures of the pyrite, both in solid masses and in the grains scattered through the altered rock of the veins and walls. The massive pyrites pass into solid, lead-colored glance, and the altered (sericitized) granite porphyry of many localities becomes dotted with grains or seamed with veinlets of glance. The pyrite grains often show all stages of replacement, first as a coating, then as minute veinlets in the pyrite, and finally complete replacement. The alteration changes sericite to kaolin.

Gossan formation is essential to secondary enrichment. Extremely rapid denudation is unfavorable for gossan formation, as it takes away the vein before decomposition. Moderately "rapid denudation is favorable because it quickly removes the upper leached portion of deposits and enables a larger amount of lode matter to be lixiviated in a given time than would result were denudation less rapid."

These several deductions mean that rugged mountainous regions, with heavy rainfall, are less favorable than arid mountain regions.

[1] *Bulletin* Geological Society of America, vol. 14, pp. 269–276.

[2] *Transactions* American Institute of Mining Engineers, vol. xxxv, p. 3.

FIG. 12. — PHOTOMICROGRAPH OF COPPER ORE, BINGHAM, UTAH (AFTER BOUTWELL)

Association of Copper Deposits with Certain Rocks

The association of deposits and igneous rocks has already been alluded to. Deposits favor particular varieties, though no rock is invariably ore-bearing. It is sufficient at present to call attention to the fact that the great workable orebodies of North America occur in connection with monzonites and quartz porphyries, invariably greatly decomposed; that, as pointed out by Aguilera,[1] copper deposits occur in America in abundance in or about Tertiary acid eruptive rocks, such as granulite (aplite) and rhyolite, contrary to the observations of the European geologists, who affirm an intimate dependence between copper deposits and basic rocks. The presence of copper in basic rocks, and of deposits derived from them, is of world-wide occurrence. The diabases in particular appear to carry copper, but in unequal distribution, not all diabase carrying this metal. Lake Superior is the most famous example. In Chile the gold-copper veins, a type common in Atacama, Santiago, and Coquimbo provinces, are associated with moderately or highly silicious eruptive rocks, quartz diorite, syenite, quartz porphyry, rhyolite, or quartz gabbro, all often containing tourmaline. The different type of silver-copper veins shows an association with basic plagioclase-augite rocks, mainly augite-porphyries, diabase, and augite-andesite, as intrusive dikes and sheets in Jurassic limestone.

There is no invariable association of copper and any particular igneous rock. Diabase, for example, is copper-bearing in New Jersey, Virginia, Montana, and elsewhere, as shown by the deposits formed by water leaching and by direct test,[2] but very few of the known bodies of the rock carry copper. That no such association is recognizable may be due to the fact that our ordinary rock classification is defective, giving no weight to relative proportion of the heavy minerals present, or due to the fact that the metal follows its own law of segregation, independent of rock segregation. Selective association is a recognized law, each mineral preferring or tending to occur in association with certain minerals (or elements) rather than with others.

The association of copper deposits and granitic rocks, such as quartz monzonite and quartz porphyry, is observed at all the great copper districts of Montana, Utah, Arizona, Japan, and in many parts of the world. Its significance is explained in the chapter on "Genesis of Copper Deposits."

[1] "Distribution of Mineral Deposits of Mexico." *Transactions* American Institute of Mining Engineers, vol. xxxii, p. 511.

[2] W. H. Weed, Ann. *Report* State Geologist, 1902, p. 125.

Igneous contacts are favorable for copper deposits, especially where the rocks are limestone. The association of copper and garnet rocks — limestone altered by contact action — is common the world over, and such areas should be carefully hunted for secondarily enriched orebodies.

Copper deposits are common in sandstones, usually part of a series of Red Beds, the world over. As a rule the copper staining is prominent, and rich ores occur where organic remains have precipitated the copper. Workable deposits are, however, rare, including those of Perm (Russia), of Mansfeld (Germany), and Coro Coro (Bolivia). The immense deposits of Katanga, central Africa, are in sandstone, but whether with red beds or not is not known. Similar deposits occur near Coyame (Chihuahua, Mexico).

No general rules for prospecting can be based upon these facts. The local district must be studied and its characteristic associations known if one would be a successful prospector.

From what has just been said, it is evident that copper deposits, like gold, may be found almost everywhere. The *primary* ores are governed in their occurrence by certain recognized laws; they are associated with basic rocks, or are contact deposits of acid igneous rocks. The reconcentration of the copper of such deposits in workable bodies may, however, occur in any convenient rock, though it is most apt to take place in those whose permeability or shattering or congenial chemical composition offers favorable conditions. In a few cases there is a marked preference for one rock over another; and a vein cutting through different rocks is payable in one and barren in another. The most striking example known to me occurs at Butte, Mont., where the big veins cutting through aplite are lean or even barren, but are rich in the quartz monzonite (basic granite) and lean again in quartz porphyry.

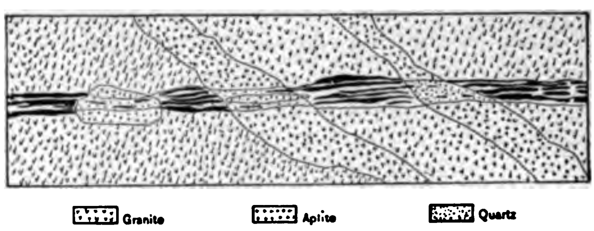


FIG. 13. — SECTION SHOWING VARIATION IN COPPER CONTENTS OF VEIN CROSSING VARIOUS ROCKS, BUTTE, MONT.

Figure 13 represents an ideal sketch of change in character of copper vein in passing from granite to aplite.

At the Dolcoath mine (Cornwall) the veins carry copper ores in slates, and tin in granite. At Schwarzenburg the copper-bearing veins form orebodies in a garnet salite actinolite bed.[1]

Differences in Depth in Primary Filling

In all the great pyritic deposits of the world, the pyritic ore, below the layer of loose sulphide ore, shows a gradual decrease in copper content with depth. In the Huelva deposits this is supposedly due to the decrease in both size and number of cracks holding secondary glance, bornite, etc., in the pyrite mass, while there appears to be also a gradual decrease of the copper content of the original and primary ore. The Tharsis ore of this district is no longer valuable for copper. In many localities original differences in depth may be noted, as at Vigsnäs, Norway, described by Vogt,[2] where seven vertical stocks of pyrite occur with 3 to 4 per cent copper in upper levels, but only 1 per cent at the 2400-ft. level, the size being constant.

In tin-copper lodes there seems to be an increase of copper in depth, followed in turn by a decrease, until, as at the Dolcoath, the tin alone is present in payable amounts.[3]

In fissure veins, below the gossan and its underlying enrichments, lies the primary vein filling. This, when an ore shoot is followed down to great depths, several thousand feet or so, shows variations in character and richness. Whether any difference exists in mineral composition between tops and roots of veins cannot be definitely answered. Few bonanza orebodies have gone to great depths; in fact, most of them are relatively shallow and are secondary ores. The low-grade, primary ores, on the contrary, go down to great depths. No definite generalization can be made, because the various types of copper deposits represent very different conditions of genesis, and hence of character of the workable ores, even where no secondary concentration or enrichment has occurred. Thus, at Dolcoath, tin ore gave way to copper in depth. Mount Morgan, long the greatest gold mine of the world, passed at 1800 ft. into a gold-bearing copper mine, while at Rio Tinto, Mount Lyell, Cananea, and elsewhere, the precious metal content and copper present rapidly decrease with depth of a few hundred feet, while the ores are rich at Butte a couple of thousand feet below the surface of the earth.

[1] R. Beck, "The Nature of Ore Deposits," translated by W. H. Weed, p. 437.
[2] "Genesis of Ore Deposits," pp. 249, 674. [3] R. Beck, *op. cit.*, p. 363.

The theory that a copper-bearing zone exists beneath the upper parts of veins characterized by galena and zinc-blende is founded more upon hope than upon fact. It is often said that such conditions prevail at Butte; but my own studies do not show this to be true. Yet the theory advanced at Butte is not without a precedent, as observations by G. A. Waller on the Hercules mine and elsewhere in Tasmania "point to the presence of a zone carrying copper ores below that of zinc and lead."[1] The discovery of large bodies of glance and enargite ore in the deep levels — 1000 to 1600 ft. — of the fault veins of the North Butte Company at Butte, Mont., is of different character. In the upper levels these veins carried only fault matter, crushed rock, and some fragments of ore.

[1] "Report on the Ore Deposits (other than tin) of North Dundas, Tasmania." *Report* of Government Geologist, 1902.

VI

GENESIS OF COPPER DEPOSITS

A CORRECT diagnosis of the genesis of an ore deposit is of great economic importance as well as of scientific interest, since it involves the interpretation of the observations upon which the engineer must base his conclusions as to the depth to which the workable ores will go down, and as to whether the size and value will become greater or less; indeed, it concerns all the factors upon which a correct estimate of the value of the deposit must be based.

Copper deposits offer a peculiarly favorable field for the investigation of ore deposition. The metal is not rare; it forms numerous natural compounds, which enter readily into solution in oxidizing; and its salts are precipitated from solution by many substances. It forms a minute but determinable part of many basic igneous rocks, though in the earth's crust as a whole it is present in exceedingly small amount. To make an ore it must usually form at least 1.5 per cent of the rock, or 30 lb. of copper to the ton,[1] a markedly large quantity compared with gold and silver, but small compared with zinc and lead.

Most of its common minerals are bright-colored and easily recognizable, the common carbonates often painting large amounts of waste, though present in very small percentage.

The studies made of copper deposits all over the world, but especially those of Norway by Vogt, Italy by Lotti, Tasmania by Gregory, British Columbia by Brock, and Canada by Coleman and Barlow, with the detailed work of the staff of the United States Geological Survey on the greatest copper mines of the world, have furnished a mass of reliable material upon which to base deductions concerning the genesis of copper ores, and by which the theories may be tested.

From these studies it is established that practically all workable deposits of copper ore are the result of concentrations effected by circulating waters, usually of atmospheric origin, which have leached lean original

[1] Except at Lake Superior, where ores of lower grade can be worked.

ores and deposited the material in an especially favorable location more or less near by. Oftentimes the evidence shows repeated concentrations. It is therefore necessary, if one would seek to know the genesis of orebodies, to trace the various steps from the primary and usually lean ores to the present deposits. This involves a discussion of the genesis of the original or primary deposit, of weathering and superficial alteration, and of the processes involved in what is commonly called secondary enrichment. In some cases, as in Arizona, there is a further weathering and oxidation, with the formation of oxide orebodies from the secondary sulphide orebodies.

Ore Deposition at the Present Time

A deposition of copper minerals as primary ores at the present time is known to take place in three different ways: (1) from volcanic emanations; (2) from hot-spring waters; and (3) from sea water.

Copper salts and copper oxide (tenorite) are deposited by volcanic vapors and gases in the rifts about active volcanoes, and tenorite occurs in scales in Vesuvian lavas (Dana), but no deposits of commercial value are being formed in this way.

Several active vein-forming hot springs are known, and at the Boulder Hot Springs, Mont., copper minerals are formed. Hot-spring waters issue from the Boccheggiano vein of Tuscany, Italy,[1] and from a Japanese deposit as well,[2] and are regarded as the final phases of ore-depositing hot springs. Cold copper-bearing waters are not uncommon, but they usually come from oxidizing ore deposits.

The deposition of copper ores in the organic muds of sea lagoons is also an admitted fact, but such deposits are scientific curiosities rather than examples of existing ore deposition. One is therefore unable to point to any example of contemporaneous ore deposition of industrial importance for a proof of the conclusions concerning genesis deduced from a careful study of copper deposits. However, as will be shown later, lean primary "ores" may furnish the copper for secondary concentrations that are workable.

Conclusions Concerning Genesis

A careful consideration of the known facts concerning copper deposits throughout the world enables one to formulate the following deductions concerning their genesis:

[1] R. Beck, *op. cit.*, pp. 426, 428. [2] "The Mining Industry of Japan," 1893, p. 30.

1. The original or first source of all the copper of ore deposits is the hot, potentially molten, material of the earth's interior.

2. The transporting agency has been first the uprising magma, consolidating near the surface as intrusive igneous rocks. Sometimes this magma differentiates to an extreme degree, and magmatic ore deposits, either acid or basic, are formed.

3. The metalliferous material forming ore deposits has (with the exception noted) been transported by igneous emanations issuing from the cooling and crystallizing rock, forming contact metamorphic deposits; deposition continued after the contact metamorphism was complete, and upper part of intrusive mass cooled, by the vapors and waters that rose through fractures from deep-seated, still hot parts of the magma.

4. Hot-spring deposits. The dying phase of igneous, or volcanic, activity is hydrothermal activity, manifested as hot springs. The waters may be entirely magmatic, or may contain admixed, meteoric, or surface waters, and form both "filling" and replacement veins.

5. The deposits formed by the various causes noted above are not commonly workable. The material must be leached and concentrated by atmospheric waters or magmatic waters to be economically valuable. Such waters form workable deposits from:

(*a*) Leaching igneous rocks (or sedimentary and metamorphic rocks derived from igneous ones).

(*b*) Reconcentration and enrichment of contact metamorphic deposits and disseminated sulphides of igneous rocks and of lean ore deposits in veins and masses.

(*c*) By reaction with sedimentary rocks, limestone, and calcareous shale.

(*d*) By absorption by fault clays and subsequent alteration to sulphide, etc.

6. Regional metamorphism causes a segregation of previously disseminated material into orebodies.

Magmatic Deposits

That the original source of all metals is the igneous magma of the earth is generally accepted. Under either the generally accepted nebular hypothesis or the meteorite theory, the first rocks of the earth were igneous; and all geologic observations point to this as the only logical inference. Concentration might result as a consequence of disintegration, decay, and sedimentation, mechanical or chemical, of the material removed.

The second hypothesis follows as a corollary of the first. That magmatic differentiation of *rocks* takes place is established beyond dispute. That it has been carried far enough to produce ore deposits is accepted as proved by many of those students of ore deposition competent to decide.

These general statements will probably be accepted by most geologists. The application of these premises to individual deposits and the relative and quantitative importance of each, as well as the detailed reactions involved in ore deposition, are matters about which there is a wide divergence of opinion. The actions of fissure filling and rock replacement; of concentration by vadose waters with secondary enrichment; of fracture, crushing, and new deposition by latent mineralizing waters, are of the utmost importance, but are later than primary ore deposition. It is essential to show, so far as evidence will warrant, the relative quantitative importance of each factor in ore deposition. Too much emphasis cannot be laid upon the statement that most workable deposits of copper ores show clear evidence of a complicated history, a succession or a combination of processes which must be discriminated upon the evidence of acceptable criteria before the truth can be arrived at. This fact is strikingly brought out in the study of the Butte, Mont., deposits, where at least four successive periods of fracturing, with faulting and ore deposition, are known, and in a different way at the Clifton-Morenci deposits, where Lindgren has worked out a very complicated history.

Eruptive Deposits. — The eruptive rocks, and more especially the basic forms, contain small amounts of various metals. As is well known, pyrite and pyrrhotite occur rather commonly in small, sparsely disseminated grains in diabase, diorite, and syenite. Thin sections show that the sulphides are intimately intergrown with the fresh, unaltered, rock-forming minerals, and are of the same age. These primary ore minerals are accessory rock constituents, present ordinarily in such small amounts as to be of no use as ores. In exceptional cases the sulphides have gathered into irregular patches or bands, before the solidification of the rock, and form true igneous or magmatic deposits. The ore mineral of these deposits is exactly the same as that which is sparsely scattered through the adjacent rock.

Iron pyrite occurs in extremely fresh undecomposed rocks, which, examined in thin section, show such conditions of microscopic intergrowth with the other minerals that there can be no doubt of its primary nature. The quartz monzonite of Elk Park, 15 miles north of Butte, shows primary pyrite and primary chalcopyrite,[1] and, according to Beck, the "diabase of the eastern Harz, the tourmaline granite of Predazzo, and even the younger lavas of the Capo di Bove (Alban Mountains) carry granules of copper pyrite." Pyrrhotite has been observed by me associated with fluorite in absolutely unaltered and glassy tinguaite (phonolite) dike-rocks of the Bearpaw Mountains. The deposits of Norway have been carefully studied by Vogt, whose work proves that the occurrence of the ore is as shown in Figs. 14 *a* and *b*, and that the ore

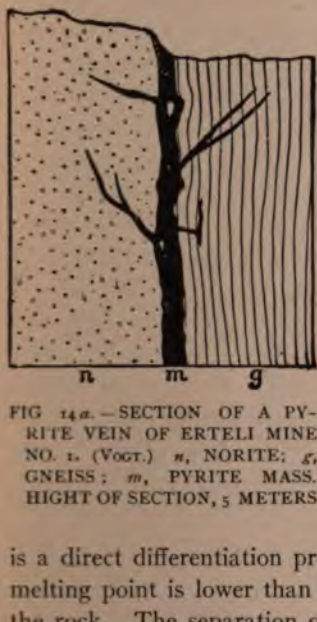


FIG 14*a*. — SECTION OF A PYRITE VEIN OF ERTELI MINE NO. 1. (VOGT.) *n*, NORITE; *g*, GNEISS; *m*, PYRITE MASS. HIGHT OF SECTION, 5 METERS

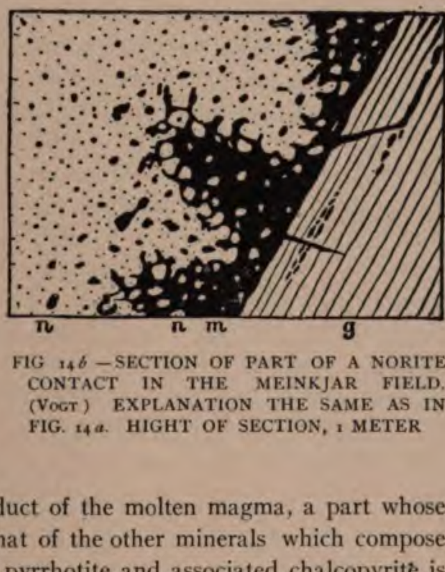


FIG 14*b* — SECTION OF PART OF A NORITE CONTACT IN THE MEINKJAR FIELD. (VOGT) EXPLANATION THE SAME AS IN FIG. 14*a*. HIGHT OF SECTION, 1 METER

is a direct differentiation product of the molten magma, a part whose melting point is lower than that of the other minerals which compose the rock. The separation of pyrrhotite and associated chalcopyrite is supposed to be akin to the separation of copper matte from slag.

The silicates were formed after this segregation of the metal, the still fluid pyrite (and chalcopyrite) filling the spaces between the various silicates, and itself congealing upon further cooling.

In most cases described both deposit and rock have been subject to strong regional metamorphism, raising a doubt as to whether the ore segregated is not a result of that process.

Theory of Sulphide Differentiation. — In a fused rock or magma composed of a solution of several silicates, oxides, and sulphides, and

[1] In specimen kindly sent me by H. V. Winchell and studied in this section.

some rarer compounds, the least soluble constituents crystallize out first, and those first crystallizing would tend to become concentrated in the first cooled portions of the magma. This portion would be along the borders of the intrusion next the wall rock. In an elliptical mass the ends would cool most rapidly, the early formed minerals accumulate, and the deposit localized here would, by the law of mass action, cause a further gathering at such places at the expense of other portions of the wall space. The escape of sulphurous gases through the still molten rock along the contacts would produce sulphides of the metals in that locality, even though the general conditions of the mass were oxidizing. The sulphides of the metals would presumably be formed in the order of their decreasing affinity for sulphur; and, according to this law, copper would be the first to form as a sulphide, as (according to Vogt) copper has a greater affinity for sulphur than any of the other metals. These principles would account for the abundant presence of copper sulphide about the borders of many basic intrusions. As a rule, the ferro-magnesian silicates are richer in the metals than the intrusive rocks as a whole, the metals appearing in them either as bases or as metallic inclusions.

Contact Metamorphic Deposits

The class of contact metamorphic ore deposits, to which an ever increasing number of deposits is being referred, embraces orebodies formed within stratified rocks under the influence of contact metamorphism near or along the boundary between plutonic eruptive masses and other rocks. The most important criterion for the recognition of these deposits is their mineralogical composition, the ore being characterized by the presence of certain minerals, such as garnet, wollastonite, epidote, vesuvianite, etc., which are known to be typical of igneous contact zones. The metamorphic change may be a simple recrystallization of material already there, that is, simple metamorphism which may be likened to the burning of brick, or it may be contact metasomatism, that is, a change of form and substance due to the addition of material by gases and vapors emanating from the igneous rock. Copper deposits are not formed by the simple baking of rocks, though the attendant loss of carbon dioxide and water with resulting smaller volume and porosity often makes such a bed a favorable channel or receptacle for subsequent mineralization. On the other hand, contact metasomatism often results in the formation of orebodies, particularly when the altered rocks are limestones. It is important to note that the evidence shows that the change is complete before the solidification of the igneous rock causing it.

Deposits of this kind possess a distinctive character of structure and mineral composition unlike that of ordinary mineral veins, but closely similar to that of the pneumatolytic (meaning formed above the critical temperature of water) or tin-copper veins.

According to Lindgren, "the genesis of the contact deposits of the Kristiania type . . . seems to be due to aqueous gas above the critical temperature, which was more or less laden with metallic compounds, and under heavy pressure penetrated the limestones adjacent to the igneous intrusive body. The temperature must have been high, but generally below the melting point of ordinary rocks. Carbon dioxide was evidently not an active reagent, for the principal reaction consists in its expulsion from the limestone. Everything points to the conclusion that the metallic substances were given off by the cooling magma."[1] Ore deposition and metamorphism were synchronous, and were completed before the solidification of the igneous rock. Later vapors or waters arising from the still heated lower parts of the magma may in some cases have added to the earlier deposit.

The pneumatolytic origin of tin deposits is generally accepted. Such deposits, notably in Cornwall, contain both tin ores and copper ores, with distinct zones in which one of the metals predominates. It is known that such veins are due to the mineralizing vapors given off by cooling granitic masses. The actual source of the mineralizing vapors is believed to be the same as that of those forming the contact metamorphic deposits proper, i.e. a deep-seated and still liquid part of the general magma, which in cooling and consequent crystallization must eliminate the vapors of the magma, squeezing it out, as it were, and as all the other constituents of the ores, fluorine, chlorine, etc., included, occur in pegmatites and are directly derived from the granite, the copper may also be so derived.

The best-studied examples of contact metasomatic and associated pneumatolytic vein formation are those of Clifton-Morenci, Bingham and Bisbee in this country and those of the Kristiania region in Norway. Their origin may be stated to be as follows:

A mass of molten monzonite was intruded in limestones and shales. The vapors given off by the cooling and crystallization of the magma, together with the heat of the molten rock, metamorphosed the limestones to a compact impervious rock, composed of various contact metamor-

[1] "Genesis of Ore Deposits," Pub. by Am. Institute of Mining Engineers, p. 729.

phic minerals, notably garnet, epidote, etc., carrying disseminated, intergrown, cupriferous pyrite. Slightly later the solid monzonite was fractured, sheeted and crackled by cooling stresses, and possibly by the earth movements common in times of volcanism. This fracturing permitted the escape of further magmatic emanations from the deep-seated, still molten reservoir. These emanations were similar in kind to those given off by the upper and now solid monzonite. They circulated in the fissures and through the masses of crushed monzonite, and, permeating the monzonite itself, mineralized it in the fracture planes and in the mass of the rock with cupriferous pyrite, and at Bingham with chalcopyrite. At most of the localities the ores formed by this impregnation were of too low a grade to work directly. The mineralization was accompanied by intense alteration and silicification of the upper crust of the monzonite, the part which is now seen. Lindgren describes a case of a clean-cut, narrow fissure at Morenci, which ran into the monzonite and was connected with the mineralized area of shattered rock. The disseminated ores are often alongside of and connected with fissures, and these fissures were the channels by which the vapors from the deep-seated magma reached the upper regions and spread out in the permeable and shattered porphyry. In cases where the fissures cut the limestones of the contact zone, this rock was not altered or mineralized.

Hot-spring Deposits

The original formation of many copper veins is generally believed to be due to hot waters rising from great depths. Such hot waters are believed to be mainly a dying phase of igneous activity, the so-called "after effects" of the intrusion of granitic masses. That atmospheric waters may penetrate to deep-seated hot rocks and rise as thermal springs is also probable, and such waters could leach the rocks traversed by them and mingle with magmatic waters. The origin of copper veins such as those of Ashio (Japan), Butte (Mont.), and of Wallaroo and other places in Australia is, like that of mineral veins generally, due to the work of rising hot waters. The conclusions concerning such deposits and the source of their mineral contents is aptly put by Geikie as follows: "The general deduction appears to me to be well founded that, while lateral segregation must be recognized as a possible contributing cause, the main agency in the formation of mineral veins is to be sought in the ascent of heated waters which could only have derived their pneumatolytic efficacy from the internal heat."[1] This conclusion accords

[1] Sir Archibald Geikie, "Text-book of Geology," 1905, p. 811.

well with the facts observed in the Butte mines, where the orebodies occur surrounded by rocks altered by solfataric agencies.

It is true that the fresh rock away from these belts of alteration carries copper as pyrite and chalcopyrite; but inasmuch as the quantity of copper present in the altered exceeds that in the fresh rock by many times, the altered rock is not leached but is enriched. It is probable that fracturing permitted the escape of uprising magmatic vapors from the still hot, deep-seated parts of the granite mass, and that these vapors produced the solfataric alteration adjacent to the lodes and deposited their copper contents by replacement of the sheeted rock alongside of the fissures. It seems to me that the presence of the copper in the fresh granite is confirmatory proof that the molten magma held cupriferous material and that its emanations were presumably metalliferous.

I have observed in many veins a decided change in the nature of the vein filling at different depths. It is believed that this, so far as it is primary, is due to its deposition by hot springs in the manner assumed in my theory.[1] Briefly stated, this assumes that hot waters exist at great depths and under great pressure, where they can dissolve and take up many ordinarily insoluble substances. At less depths saturation obtains, owing to loss of pressure; still nearer the earth's surface the less soluble substances, metallic sulphides, etc., will be deposited in the inverse order of their solubility, forming zones in which certain minerals will predominate at different levels. When the hot waters reach the surface only the readily soluble substances, such as the alkaline carbonates and chlorides and silica, will be in solution and pass off.

This theory of a vertical distribution of ore in hot-spring pipes has been independently advanced by J. W. Gregory[2] and by J. Parks[3] as well as by me.

ORE DEPOSITION BY CIRCULATING WATERS OF ATMOSPHERIC ORIGIN

Atmospheric waters descending through the rocks of the outer crust of the earth form an agent of great importance in the solution, redeposition, and further concentration of ores in the upper part of copper

[1] "Mineral Vein Formation at Boulder Hot Springs, Mont." Twenty-first Annual Report of United States Geological Survey, 1900, part ii, pp. 227–255.

[2] "Factors that Control the Depth of Ore Deposits." *Transactions* Australasian Institute of Mining Engineers, vol. viii, 1904, p. 2.

[3] *Australasian Mining Standard*, February 2, 1905, p. 152.

veins and deposits. The leaching of rocks containing minute amounts of copper, such as diabase and basalts, by the slow-moving groundwater seepage, produces hydro-metamorphism. This process has gathered the copper from the body of the rock and deposited it in open spaces, such as vesicules, joints, or cracks, etc., or carried it out of the rock to be deposited near by in the shale or schist. The copper deposits of the northern Rockies of Montana and the Belt range occur only where there are intrusive bodies of diabase, and then only where the rock is much altered and decomposed.

That diabase is the source of the copper of such deposits is established beyond question by chemical tests. Moreover, pyrite is present in almost every thin section of these rocks, as it is in the Triassic traps of the Southern States. Coming into solution in the hydro-metamorphism of the diabase, it is precipitated in the clay shales by absorption (Sullivan reaction) or by a reduction due to organic matter.

The trap rocks of New Jersey are permeated by surface water containing carbon dioxide and alkaline and earthy sulphates in dilute solution. These waters dissolve copper and iron out of the trap and carry it into the adjacent sandstones, where the slow decomposition of the sulphates by organic matter forms soluble sulphides (alkaline), and these change the iron and copper salts to chalcocite or pyrite or chalcopyrite; the bases, alkaline or earthy, being carried off as carbonates in the further slow movement of the water.

According to L. de Launay,[1] masses of argentiferous bornite, chalcocite, and chalcopyrite, found in films and veinlets about or in grains in basic igneous rocks, are formed in this way.

The occurrence of native copper in small quantities is common in copper deposits the world over. The Lake Superior deposits are a remarkable and exceptional instance and have no counterpart. They are worked to a depth of 5028 ft. below the surface, and have been carefully studied, yet the question of their genesis is still regarded as unsettled. The copper is in conglomerates of volcanic rock (not volcanic conglomerate) and in old surface flows.

Some geologists contend that the metal has been deposited from ascending waters by the reducing action of ferrous solutions on copper salts. Palmer[2] remarks, however, that if any of the cuprous sulphides are oxidized, half of the copper can be carried off in solution as cupric sulphate, but the other half will remain insoluble and, if unoxidized,

[1] "L'Argent," p. 108.

[2] "Chemistry and Metallurgy of Copper." *Engineering and Mining Journal*, December 8, 1904, p. 908.

as native copper. The theory held by Lane and others is that the copper comes from the basic lavas, and it is an exceptionally good case of local concentration and metasomatism.

Pumpelly[1] considers the process of replacement to have been, first, formation of chlorite in the amygdaloid rock; second, individualization of non-alkaline silicates, as laumonite, prehnite, epidote; third, deposition of quartz; fourth, introduction of native copper, accompanied by a replacement of prehnite by a green earth or delessite, often intimately connected with the copper; fifth, appearance of orthoclase, analcite, and other alkaline silicates. Pumpelly assumed that the copper was originally present as sulphides in the rocks, and that the leaching and redeposition in veins have been effected by surface waters carrying carbonic acid and some atmospheric oxygen. The copper was deposited after the destruction of the ferro-magnesian minerals and before the deposition of products from the decomposition of the feldspars. The copper was converted from the sulphide state to silicate, carbonate, and sulphate, these salts being reduced to the metallic state. He considers that there is a close genetic relation between this metallic copper and the ferric condition of the iron oxide in the associated silicates, believing that the oxidation of the iron was caused by the reduction of the oxide of copper at the expense of the oxygen of the copper oxide.

There is no doubt that the copper was deposited by water, in porous sandstone and conglomerates, or more often in porous upper parts of lava flows.

It is true there are faults running with the bedding, but somewhat steeper, as seen by slickensides on top of the Calumet and Hecla lode, and in Kearsarge conglomerate at the Central mine. At the latter place the copper lies above the clay slip.[2] The evidence thus points to Pumpelly's theory of descending waters, rather than to Van Hise's theory of ascending waters, as the true genetic factor. In the deeper part of the Quincy mine, Dr. Koenig has found waters now depositing copper. The shallow waters down to 500 to 600 ft. are high in alkalies and low in chlorine and zeolite forms. Those of deep working—as the 4600-ft. level of Quincy—are strong brines. Their chlorine and bromine seem to be of igneous origin, and original and occluded in the lavas.

[1] "The Metasomatic Development of the Copper-bearing Rocks of Lake Superior." *Proceedings* American Academy of Arts and Sciences, vol. xiii, 1877–1878, p. 253.

[2] State Geological Survey, vol. v, part iv, pp. 86–94. A. C. Lane, Annual *Report*, 1903.

It is believed that Lane's theory best agrees with the facts, that the copper comes from the traps; original water and gas have been important factors in bringing the copper into solution, as the water circulation which finally precipitated the copper was downward.

The theory that the copper deposits of serpentines originate by a segregation of the original content of copper of the basic rock during its serpentinization is merely an extension of the process long recognized and accepted for the origin of chromium ores. Von Groddeck [1] says: "These pyritic segregations can also be produced in time . . . in nearly the same manner as chromic iron in the transformation of peridotite into serpentine."

Genesis of the Pyrite Deposits of Crystalline Schists

The genesis of the bodies of pyrite which furnish the bulk of the output of foreign copper mines, and much of the material for the manufacture of acid, has long been a subject of contention among students of mining geology. Despite the advances in our knowledge of rocks and ores made in recent years, owing to the application of the microscope to the study of thin sections, and to the new light thrown on ore deposition by the discoveries concerning the properties of dilute solutions, no general agreement has been reached by geologists concerning the origin of these perplexing orebodies. The general characters of this class are the same everywhere: the deposits are of large size, occur in crystalline metamorphic schists, and may be regarded as bedded veins. The Spanish deposits, the largest in the world, occur near igneous masses, and the metamorphism of the adjacent rocks has been regarded as a result of contact action. In some examples, however, the rocks are incased in schists of undoubted sedimentary origin, and, therefore, have been regarded as sedimentary deposits. Indeed, Klockmann has recently expressed his belief that many of these pyrite deposits are original sedimentary deposits and similar in origin to the nodular masses of iron ore found in shales and clays; but the eminent Swedish investigator, Vogt, has regarded deposits of the Huelva type as due entirely to eruptive after effects.

The American deposits of the Alleghany region have been long worked and commonly regarded as typical of this class. Many observers have regarded them as of sedimentary origin, an abnormal deposit in the rocks of the region, and altered with them. They all occur in a belt of talcose schists, whose general characteristics are similar from Alabama to Canada. In recent years this simple theory of sedimentary origin and

[1] "Die Lehre von den Lager stätten der Erze," French translation, pp. 194, 378.

subsequent alteration has been disproved by a careful study of structural relations of the different deposits and a microscopical study of thin sections of the rocks.

The two diametrically opposed theories of Vogt and Klockmann can therefore be tested by the facts observed in this region. Briefly stated, Klockmann maintains that these pyrite deposits are, broadly speaking, contemporaneous with the rocks; that metamorphism did not generate pyrite deposits, but found them ready-made, and altered them, as it did the rocks holding them. Klockmann carries his theory still further, and maintains that orebodies of pyrrhotite and magnetite form the successive steps in the alteration of pyrite by a natural roasting or thermal metamorphism of the orebody. Vogt, as already indicated, has held that the deposits are of later origin, were introduced into the rocks mainly by pneumatolytic action, and that they are analogous to or really form bedded veins.

For the American deposits the observed facts which controvert the ingenious theory of Klockmann are as follows: First, some of the deposits occur in schists formed of sedimentary rocks (Ducktown) and others in schists formed of igneous material (Carroll county, Va.; Ore Knob, N.C.; Capelton, Quebec). Second, the Ore Knob, N.C., and Gossan Lead, Va., veins cross the foliation of the schists in dip and sometimes in strike. Third, the Gossan Lead of Virginia is a fault plane with different rocks on each side, the ore cementing a friction breccia composed of fragments of wall rock and of a deeper and unexposed rock. Fourth, the orebodies at Ducktown, Tenn.; Ore Knob, N.C.; and Carroll county, Va., are massive, inclose horses of schist, the pyrite cements friction breccia, show no evidence of metamorphism, and the orebodies are not even well jointed. It is hardly possible, therefore, that they could fail to show the results of the forces that altered the adjacent rocks to a schistose condition. Fifth, many of the smaller deposits of the Appalachian region show a constant and significant association with amphibolite.

In this connection it is well to recall the recent study of the southwest African deposits, so well described by Kunz. In that region great lenses of pyrite occur intercalated in crystalline schists, but only along a line of fracture, marked by dioritic rock at most places, the orebodies occurring where this fracture line is intersected by cross fractures, and being independent of the foliation.

If one assumes an original segregation of pyritic material, such as is found at Sudbury, both this material and the containing rock will be greatly altered if depressed beneath a heavy load, and carried down to the zone of rock flowage. Indeed, either a deposit of magmatic origin, like that of Sudbury, or one of metasomatic origin, like the gold-bearing pyrrhotite orebodies of Rossland, would be subject to a marked concretionary action when in the plastic zone. To this extent Professor Klockmann's contention is believed to be sound; i.e. that the part played by metamorphism in regard to mineral deposits has been often misconceived, if not neglected, by investigators.

Orebodies similar to the Boundary Creek contact deposits, if subjected to regional metamorphism, could be altered to the Huelva type, "concretionary" action causing a segregation of the scattered disseminate material into masses of solid ore by replacement.

Copper in Sedimentary Rocks

The copper ore found in sedimentary rocks is either indigenous or has been introduced. The only rocks containing indigenous ores are the sandstones of the Red Bed series, mostly of Permian or Triassic age, but rarely belonging to other periods. The association is not constant; for the copper only occurs locally, even in the same bed, though the phenomenon appears to be widespread, the deposits covering large though isolated areas in many parts of the world. The peculiar frequency and world-wide connection of copper ores and the red rocks of Permian and Triassic age has long been known, and no satisfactory explanation for this occurrence has yet been given. In general, these deposits, though frequent and extensive, are not worked. The Russian mines, in the government of Perm, and the famous Mansfeld mines are the only ones now productive. Nevertheless, such extensive deposits of uniform though low-grade ores form a reserve that will be utilized when richer deposits are exhausted or costs reduced. In general, these deposits occur remote from any known igneous rocks.

Under exceptional conditions, as at localities observed by Winchell in British Columbia, copper is so abundant in surface waters as to form chalcopyrite coating stream pebbles on the cement of placer gravels. It is known that even very dilute solutions of copper sulphate, shaken with or passed through pulverized rocks or clays, lose their copper, hence it is safe to say that relatively little copper exists in the sea-water, but is usually precipitated in clays.[1] This is substantiated by Forchammer's analyses and conclusions that all clay shales are more or less cupriferous.[2] Such material has, it appears, commonly suffered a slight concentration

[1] E. S. Sullivan, "Chemistry of Ore Deposits." *Economic Geology*, vol. i, no. 1, 1905.
[2] Bischop, "Chemical Geology," vol. i, p. 385.

and precipitation about and by organic matter. The hypothesis that bedded ores have been deposited contemporaneously with the inclosing sediments has received a decided set-back from these experimental determinations.

Genesis of Copper Ores in Sedimentary Beds. — As some geologists claim a sedimentary origin not only for the deposits of Mansfeld and its basin, but also for the pyrite deposits of Spain and Austria, etc., it is necessary to consider the questions: Are deposits of cupriferous pyrites forming as sediments? What evidence do existing deposits offer of such an origin? In considering this matter it is admitted that the waters of the present seas contain a small quantity of copper. According to Dieulafait, the concentrated mother liquors of the salt pans of the Mediterranean region contain so much copper that it can be determined in 5 cubic centimeters of the liquid. This amount is equivalent to 0.01 gram of copper to 1 cubic meter of sea-water. The oceanic researches of Russian scientists have shown that pyrite is being deposited in large amounts in an ooze on the bottom of the Black Sea. Moreover, in the salt lagoons a black sulphur-charged mass is deposited on the bottom when the water is left undisturbed, and in this region this material always contains copper, but it is in minute quantities, and it is concentrated in the muds that settle mechanically in the sea, thus forming the percentage of copper found in the cupriferous shales of today. The theory recently proposed by Horn — according to which these mother liquors seep downward into the underlying rocks and sediments, altering them by widespread oxidation, and gathering the copper contents of diabase, diorite, and other basic rocks, as well as any preëxisting ore deposits, into the mother liquor itself — is ingenious, but it does not explain how such liquids rise again to the basins to be suddenly overwhelmed by the gravels and sands swept in by an inrush of the sea, with accompanying precipitation of the copper contents by the organic material brought in by the flocculent sediments so formed. On the other hand, if either sedimentary or igneous rocks containing scattered particles of copper are subjected to regional metamorphism, the same causes which permit an assembling and readjustment of the molecules of the rocks themselves also permit a concretionary action and a concentration of the copper; this, however, is not sedimentation.

This widespread presence of copper in Permian rocks has long been regarded as an example of deposition by sedimentation. This belief has been greatly shaken by detailed study of the Mansfeld deposit, which shows association of the ore with veins and faults, and the peculiar concentration of values near such fissures points to a subsequent introduction. Moreover, there is a significant association of the copper with *bleached* portions of the red rocks, and with bituminous layers, an association indicating deposition after rock formation. When the beds are steeply upturned they may be either merely porous rocks, open channels for water circulation, or open courses formed by slipping on bedding planes.

The ores found in the Red Bed series are always in gray sandstones or shale, or in gray or greenish patches in a red rock. In other words, they occur where the normal oxidizing conditions necessary for Red Bed deposition were locally reversed. In many instances this is clearly the result of the presence of organic matter, and, indeed, there is abundant evidence that the reduction of the copper was due to organic matter, in the various "petrifactions" of wood, plants, and fishes seen in mining operations. But the further fact is evident that the conditions under which Red Beds formed were also, though only locally, favorable to copper deposition. The coarse material, cross-bedding, ripple marks, raindrop impressions, and abundance of plant remains all indicate that the rocks were formed as beach and shallow-water deposits. The red color and abundance of gypsum and salt beds indicate that the sands came from a long weathered and decayed earth surface, and were laid down in shallow marginal lagoons.

In the sedimentary rocks *workable* deposits of ore occur only in local areas of disturbance where the beds are cut by fissures or zones of crushing, brecciation, or faulting, a generalization advanced by W. P. Jenney.[1]

[1] "Lead and Zinc Deposits of Mississippi Valley." *Transactions* American Institute of Mining Engineers, vol. xxii, pp. 184, 192.

VII

CLASSIFICATION OF COPPER DEPOSITS

A CLASSIFICATION of ore deposits is of practical value so far as it is based upon the factors used in determining the extent and value of a deposit. Any classification must of necessity have arbitrary distinctions, while in nature one finds transitions, and thus even a genetic grouping will at times prove unsatisfactory. Primarily, a classification is useful as it permits an orderly arrangement and correlation of facts and facilitates description, because any deposit may be so classed or compared with a type that only its individual peculiarities need specific mention.

The two main difficulties encountered in an attempt to classify copper deposits are: (1) that most payable deposits consist of concentrations, perhaps many times repeated, of the copper of the lean primary ores; and (2) that the deposits of a particular place, though formed by the same mineralizing waters or agencies, and at the same time, may show so great a diversity of form, mineral composition, and structural character as to render their division necessary, though genetically they may be parts of one deposit. For example, recent studies at Bingham, Utah, and at Morenci, Ariz., have conclusively shown that emanations from a granitic magma have made deposits of various structural types, viz.

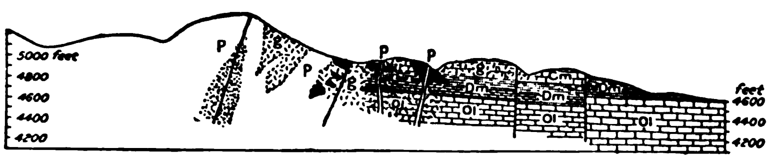


FIG. 14*c*. —IDEAL CROSS-SECTION OF MORENCI DEPOSITS

fissure veins cutting both the igneous and sedimentary rocks; deposits not connected with veins but confined to the altered limestones; the stockworks or masses of shattered porphyry (the disseminated ores). The related deposits are shown in the diagram (Fig. 14*c*). Manifestly, only a genetic classification can adequately express such relationships.

Form, though important in mining and sometimes characteristic, is not essential; the distinction into veins and masses may even separate the parts of a single deposit, as, for example, the veins and the offshoots from it, called "carbona," in one of the Cornish tin mines. Metasomatic replacement is a very important factor in ore deposition, but cannot be accepted as a distinction of the first importance, since many deposits consist partly of ore deposited in open spaces and partly by replacement.

The German classifications are based very largely upon the character of the vein filling, and the distinctions are not applied to deposits other than veins. That identical conditions of solution, physical factors, and rocks will produce similar deposits is no doubt true; but in some of the cases most carefully studied the facts show that the character of the solution must have gradually changed as it passed along the same vein, as, for example, is seen in the filling of the Boccheggiano vein of Tuscany, Italy.

In the present state of knowledge the following classification, though confessedly imperfect, seems to best express the character and the relationships of the different types of copper deposits:

CLASSIFICATION

I. Igneous deposits, formed by segregations of molten magmas.
  - A. Silicious segregations.
    - Acid granites with igneous quartz veinlets carrying sulphide ores.
      - 1. Berezovsk, Russia.
  - B. Segregations in basic igneous rocks.
    - (a) Segregated sulphides on borders of basic rock.
      - 2. Sudbury type, Canada.
    - (b) Stocks in ultra-basic rock.
      - 3. Monte Catini, Italy.
    - (c) Segregations in diorite or diabase dike.
      - 4. Cape Colony, Africa.

II. Emanation deposits, formed by vapors and gases emanating from molten igneous material (at or above 364 deg. C. and a pressure of 200 atmospheres).
  - A. Contact metamorphic deposits.
    - (Characterized by a gangue of garnet, epidote, actinolite, etc., with specularite and magnetite.)
    - (a) In metamorphosed limestones and calcareous rocks.
      - 5. Kristiania type, Norway.
    - (b) In igneous tuffs.
      - 6. Boundary Creek, B.C

B. Deposits due to igneous vapors and gases, eruptive after effects from cooling magmas.
7. Tin-copper deposits, Cornish type, England.
8. Fissure veins and crush zones, Morenci type, Arizona.
9. Tourmalinic copper veins, Thelemarken type, Saxony.
10. Fluoritic copper deposits.
11. Augitic copper veins, Tuscany, Italy.

III. Deposits formed by hot ascending waters — hot-spring deposits.
Condensed emanations from igneous rocks (primitive waters) or those mixed with atmospheric waters.

A. Deposits filling cavities.
12. Quartz veins, Virgilina type, Virginia, United States.
13. Impregnated sandstone, Coro-Coro type, Bolivia.
14. Crushed breccias, Nacozari type, Mexico.
15. Tuffs and conglomerates, Kosaka type, Japan. Boleo Mexico.

B. Replacements of rocks.
16. Quartz-pyrite veins, Butte type (sericitic).
17. Spathic copper deposits.
18. Biotitic copper deposits, Rossland type, British Columbia.
19. Copper-silver veins, Peruvian type.
20. Gold-copper veins, Chile. (Cupriferous gold quartz formation.)

IV. Deposits formed by atmospheric waters.

A. Superficial.
(a) Mechanical.
21. Copper placers, Alaska, Philippines.
(b) Chemical.
22. Chalcopyrite under bogs.
23. Malachite deposits, Texas.
24. Cementing gravels, Kelvin, Ariz.; Alaska.

B. Underground waters.
(a) Filling cavities.
25. Conglomerate deposits.
(b) Replacement.
26. Amygdaloid beds.
(c) 27. Hydrometamorphism, Blue Ridge type.

V. Metamorphic deposits (dynamic and regional).
(a) 28. Deep-seated alteration, serpentinization with segregation of sulphides, Catini, Libiola, Italy; Wis, Rebelj, Servia; Coritza, Turkey.
(b) 29. Regional, Ducktown, Cullowee.

VI. Sedimentary deposits.
30. Mansfeld, Germany.

For many deposits the available data do not permit a positive conclusion as to their genesis, especially where pneumatolytic (gas-aqueous) conditions are indicated. In such cases they are perhaps best included with the deposits formed by hot springs. The evidence does not warrant, in my opinion, putting the ore deposits of the Huelva, Spain, region with the contact deposits, and until further data are at hand they may be best grouped as metamorphic, in a class to include the so-called bedded veins of the pyrite deposits generally. Mount Lyell is included here, though their study by Gregory[1] shows them to be leached pyritized schists whose material gathered in fault planes, though the origin of the copper of the schists is still in doubt.

The distinctive features of each of the groups and classes given in the above table will be given in the succeeding part of this chapter, but the reader is referred to the detailed account of the type deposit for full information. The number of copper deposits that are worked on a large scale is relatively small, but there are many thousands, more or less developed, representing various types, and some of them destined, perhaps, to make good mines. To attempt to describe each deposit would be unwise. Therefore the best-known or best-described deposits are taken as types, following Von Groddeck's idea, and these types fitted into what appears to be their proper place in the classification. It is evident, even if experience should prove the assignment to be wrong, that the reference of any deposit as being of any particular type is both convenient and in accord with the known facts, regardless of one's views as to its exact genesis. To refer a deposit to the Huelva type, for example, is to convey a definite idea as to its general characters, though the genesis of the Huelva deposits is a matter of controversy.

I. Igneous (or Magmatic) Deposits

The deposits of this group consist of the same minerals that are sparsely disseminated through the inclosing igneous rock, concentrated in compact masses. The conditions of microscopic intergrowth of ore and rock forming minerals and their freshness, together with the structural character of the deposit, prove an igneous origin; but it is necessary to look sharply for evidence of segregation of the sulphide by metamorphic agencies or later thermal waters, as so many of the deposits supposed to be of this class are found in metamorphic rocks. The evidence

[1] "The Mt. Lyell Mining Field, Tasmania, with Some Account of the Geology of Other Pyritic Ore Bodies." *Transactions* Australasian Institute of Mining Engineers, vol. x, pp. 26-196.

for silicious segregations is not regarded as conclusively proving an igneous origin; they may belong under Group II.

1. *Berezovsk Type.* — The veins of this place carry chalcopyrite and other ores, auriferous pyrite and free gold with tourmaline as a frequent accessory, in a number of small quartz veins of a ladder lode, in an aplite dike. They are regarded by Beck as segregations of silicious water-rich material from a granite magma of normal composition. Pegmatite dikes carrying chalcopyrite and pyrite also occur near Anaconda, Mont., and elsewhere in America.

2. *Sudbury Type.* — The deposits of this type consist of chalcopyrite with much greater amounts of pyrrhotite and pyrite, with more or less admixed rock material. These sulphides occur as accessory constituents of the inclosing rocks. The form is rudely lenticular, and the masses are found "crowded into bay-like indentations in the adjacent rocks or strung out along the narrow offshoots of the mother rock (norite) like sausages on a string, but with a long piece of string between them." The lenses conform more or less closely to the foliation of the rock. There is a sharp contact between ore and the outer wall rock, but a fading of ore into the mass of the parent rock.

3. *Catini (Italy) Type.* — The orebodies occur in the body of a mass of olivine gabbro or of diabase. The ores consist of pyrite, chalcopyrite, bornite, and glance, with rare blende and galena, all as disseminated particles, sometimes gathered into nodular masses incased in serpentinized rock. The orebodies are sometimes concentric in structure with a nucleus of chalcopyrite, a shell of bornite, and an outer crust of pyrite.

The form is irregular and roughly spherical masses, lumps, etc., or many-armed and branching stocks. The orebodies are irregular in shape, size, and distribution, but the serpentine about them contains ore enough to work. The pay ore is confined to the serpentine, crushed and broken by expansion and fracturing. The type includes the Libiola and other Ligurian deposits in Italy, and occurs at Wis and Rebelj in Servia and at Minas, Cuba, and is common in Turkey.

4. *Cape Colony Example.* — The ores consist of chalcopyrite and bornite mixed with diorite. The orebodies are lenticular and occur in diorite dikes, where they are intersected by barren fissures. The ore minerals occur as accessory constituents of the diorite, replacing the hornblende and mixed with the other rock minerals. There is some doubt as to whether the deposit is actually a primary igneous segregation, and not a later concentration of lean, igneous ores along fissure intersections.

Following are the conclusions concerning deposits of direct igneous (magmatic) origin (excluding those segregated during alteration of the rock, as Catini):

1. The orebodies occur only at the contact, and must be looked for along that line.

2. They are sharply defined from the adjacent rock, but fade off into the mother rock in bunches, scattered nodules, etc.

3. They are bunchy and often of irregular distribution.

4. They are very rare, the only examples in America now being worked being those at Sudbury.

II. Deposits due to Igneous Vapors and Gases, Eruptive After Effects, from Cooling Igneous Magmas

The term "contact metamorphic" or "metasomatic" deposit is used to designate the masses and beds in the intensely metamorphosed limestones forming the contact zone about eruptive masses. The mineralogic composition is the most important criterion for the recognition and discrimination of deposits of this class. The ore is characterized by the presence of certain minerals, which are known to be elsewhere typical of igneous contact zones. Where the ore has, as is usually the case, metasomatically replaced limestones, dolomites, or other rocks containing carbonate of lime, the contact minerals are garnet, epidote, light-colored pyroxene, wollastonite, vesuvianite, and other lime silicates. In shales the aluminous contact minerals, andalusite, cordierite, chiastolite, scapolite, etc., occur. The most important copper minerals are pyrite and chalcopyrite, usually accompanied by pyrrhotite and magnetite.

The conclusions regarding contract metamorphic deposits are as follows:

"Although cases may be easily conceived in which the deposits would continue in depth and length for several thousand feet, it is far more common to find them irregular and spotted in their mineralization, so that while there is no genetic reason why they should not be continuous to the greatest depths attainable in mining, they will as a matter of fact often give out when least expected." [1]

5. *Kristiania Type.* — The ores consist of the minerals mentioned above, with specular iron, magnetite and the sulphides noted. Molybdenite is often an accessory mineral; and in many examples galena and sphalerite occur, thus differing from the original type. The structure is

[1] W. Lindgren, "Ore Deposits and Deep Mining." *Economic Geology*, vol. i, p. 36.

prevailingly irregular and pockety for deposits at the contact, but less so for the altered beds of the contact zone at a greater or less distance from the actual igneous border. The best-described examples are at Morenci, Ariz.; Bingham, Utah; and San Jose, Tamaulipas, Mexico. Other examples occur at Bisbee and at Cananea (Greene Copper Company), Jibosa mine, Chihuahua, and Chiapas, Mexico, in the Banat Mountains of Hungary and the Ural Mountains. The type is common in the western United States and Mexico.

Form. — The deposits generally follow the contact, but are extremely irregular in detail, and almost always very bunchy. No regular law has been recognized as governing the form of the orebodies, which are sometimes lenticular masses.

Position. — The minerals generally occur in the limestone or calcareous rock, immediately on the contact, from which they rarely extend more than a hundred feet. Usually they extend much less than this.

Constituent Minerals. — The gangue contains garnet, wollastonite, epidote, ilvaite (lievrite), amphibole, pyroxene, zoisite, vesuvianite, quartz, and calcite, rarely fluorite and barite. The ore-minerals are specularite, magnetite, bornite, chalcopyrite, pyrite, pyrrhotite, and, more rarely, galena and zinc-blende. The sulphides may carry some gold and silver, usually more of the latter than of the former, but are rarely rich. Tellurides are unknown. The characteristic feature is the association of the oxides of iron with sulphides, and the presence of various silicates of lime, magnesia, and iron. The deposits are throughout metasomatic, having been formed by the replacement of limestone; and the filling of open spaces is almost entirely absent. On account of the great solubility of the limestone, well-developed crystals of the gangue minerals are very common.

Exceptions. — There are some classes of deposits which, though presenting a certain similarity to this type, must be strictly separated from it. Among these are contact deposits between limestone and igneous rocks which carry as metasomatic products (besides galena and zinc-blende) sericite, dolomite, siderite, and quartz, and which, upon close investigation, are as a rule found to be related to fissures and faults.

6. *Boundary Creek Type.* — Bands and irregular stock-shaped masses of impregnated and replaced greenstone tuffs. The ores consist of pyrrhotite with chalcopyrite, magnetite, and some pyrite, with associated calcite, amphibole, actinolite, garnet, and other contact minerals. The

deposits are associated with contact metamorphic limestone deposits. The type locality is at Phœnix, in the Boundary Creek district, British Columbia.

7. *Tin-copper Deposits of Cornwall, England.* — This group is characterized by the presence of greisen or of *Zwitter*, in which the ore minerals occur alongside of the usually small and unimportant fissure vein that acts as a feeder. Greisen is an altered granite, a product of pneumatolytic action. It is a granular rock consisting of quartz and white mica, usually lithia- and fluorine-bearing, which carries accessory cassiterite, chalcopyrite, and often topaz. The feldspar and biotite of the original rock are gone, and new minerals added. Where the wall rock is schist or shale the product of alteration is different, and is called *Zwitter* in Germany.

Veins of this type usually carry tin in the gossan and have a copper-bearing zone below that gives way to tin ore, with only traces of copper in depth. The Dolcoath vein is the best-known example; it has pay ore at 2490 ft. in depth. Other examples are abundant in Germany.

8. *Morenci Type, Quartz Copper Veins.* — The veins of this type are characterized by a quartz gangue with specular hematite and molybdenite, with granular massive pyrite. They are due to the pyritic replacement of the wall rock of well-defined fissures in the various rocks near igneous contacts, but are especially productive in the granites and porphyries. The Bingham (Utah), Boundary Creek (Canada), and Moonta (South Australia) veins are examples. The type grades into No. 9. The most important ore deposits of this nature are not veins, but are the disseminated ores in the porphyry adjacent to fissure veins, as at Morenci. They consist of fractured porphyry (or of granite in some cases), with the joint planes and the mass of the rock coated and impregnated with pyrite, chalcopyrite, and blende.

Deposits of this type are seldom workable except where secondary enrichment has taken place by the action of surface waters, and in this case the rich ore does not usually extend more than 400 ft. below the gossan.

9. *Tourmalinic Copper Veins, Thelemarken, Saxony, Type.* — These veins are distinguished by a gangue characteristic of tin deposits and formed of quartz and tourmaline with much altered and tourmalinized wall rock. The ores consist of pyrite, chalcopyrite, and bornite, rarely some glance, with accessory specular hematite, molybdenite, galena, sphalerite, and sometimes arsenical and bismuth and uranium ores. The gangue is quartz with tourmaline needles, muscovite, calcite, dolomite, siderite, fluorite, beryl, apatite, anastase, and zircon. Any or all of

these minerals may be present. The wall rock is greatly altered, and the feldspar replaced by quartz and mica. Veins of this kind occur in granite or slate of the contact zones, as ladder veins in granite (aplite) dikes like type 1. (Examples: Skykomish, Washington; Aamdal and Svartdal, Norway. Compare with the gold-copper veins of Remolinos, Ojancos Tamaya, La Higuera, and Las Condes, Chile.[1])

10. *Fluoritic Copper Veins, Vogtland, Saxony, Type.* — This type is an aberrant form of the spathic copper deposits, agreeing in this respect with the closely allied tourmaline copper deposits, and thus approaches the tin deposits in character. The Auf der Kunst vein is a typical example, consisting of a footwall band of siderite and copper ore; a second streak contains the same ores in a gangue of quartz and fluorspar; and a middle band is 6–25 ft. thick, and consists of white and green fluorite, with a hanging wall layer of barite containing violet fluorite and copper ores. The type is rare.

11. *Augitic Deposits, Tuscan Type.* — The best-studied example is the Temporino vein of the Campiglia Marittima, Tuscany. The ore consists of chalcopyrite and pyrite, with less amounts of galena, sphalerite and arsenopyrite in a gangue of manganiferous augite, forming round masses of radiating fibers which have the copper ores between the needles or as a core. The ore occurs as an alteration product of Liassic limestone at the contact with a "mixed" dike of augite and quartz porphyry. Stringers of this ore extend out into the country rock for many feet along fractures.

III. Deposits formed by Hot Waters. Hot-spring Deposits

12. *Quartz Veins, Virgilina (Virginia) Type.* — Simple fissure filling of quartz with bornite and chalcopyrite and some pyrite. The quartz is coarsely crystalline and markedly different in appearance from that due to replacement; the vein walls are little altered. As mentioned under "Genesis," there is every transition from the pneumatolytic veins through the wandering of the watery vapors farther and farther from their source into the country rock, until the veins are of the ordinary fissure type. According to the descriptions given by various authors, many of the veins of Australia and of Japan are of this type.

13. *Impregnated Sandstone, Coro-Coro (Bolivia) Type.* — Beds of

[1] W. Lindgren, "Metasomatic Processes in Fissure Veins." *Transactions* American Institute of Mining Engineers, vol. xxx, p. 578. *Idem*, "Genesis of Ore Deposits," p. 546.

more or less pure white and gray sandstone with fissures and the spaces between the grains filled by a more or less uniformly diffused cement of copper sulphides and sulphantimonides and arsenides. Where weathered the cement is malachite. Examples occur at Coyame, Chihuahua, Mexico; at Camaquam, Brazil; and at Katanga in the Congo Free State, all of which are described in the present volume.

14. *Porphyry Breccia, Nacozari (Mexico) Type.* — A breccia of altered and crushed felsitic rhyolitic porphyry, in part broken shells of decomposition boulders, long slivers of porphyry, cemented by chalcopyrite and accessory quartz. This grades into crushed porphyry with disseminated sulphide ores.

15. *Impregnated Tuffs and Conglomerates, Kosaka (Japan) Type.*— Copper minerals impregnating and cementing clastic volcanic rocks, which may or may not be water-worn. Boleo (Mexico) deposits consist of manganiferous copper ores, as described later.

16. *Quartz-pyrite Veins, Butte (Mont.) Type (Sericitic Copper-silver Veins).* — Quartz with pyrite in greater or less amount and with occasional blende, in replacement veins with the wall rock altered to quartz, sericite, etc., in wide zones on each side of the veins. The veins often shade off into wall rock, except where later movement has made a new selvage. Carbonates are absent. Besides pyrite, which is cupriferous, and the secondary glance which is formed from it, at the Butte mines, primary enargite and bornite and rarely tetrahedrite occur.

The largest producing deposits of today are quartz veins, as, for example, those of Ashio, Japan, and of Australia, besides those of Montana; but there is not enough evidence to make a definite assignment of many veins to this class.

17. *Spathic Copper Veins, Kamsdorf (Thuringia), Germany.* — Fissure veins with replacement; the filling consists of various carbonates, particularly siderite, calcite, and dolomite. Barite is very common and is at times accompanied by fluorite. Chalcopyrite with tetrahedrite, bornite, glance, and accessory nickel and cobalt ores occur.[1]

18. *Biotitic Copper Deposits, Rossland Type.* — Well-defined fissure veins in various granular intrusive rocks. The ore consists of pyrrhotite with chalcopyrite and a little arsenopyrite, all gold-bearing. These sulphides lack crystalline outlines and are clearly replacements, as the ores fade out into the country rock and are a replacement of it along narrow fissures. The chief gangue mineral is biotite, with which a little

[1] R. Beck, *op. cit.*, p. 226.

calcite, quartz, amphibole, tourmaline, chlorite, muscovite, and garnet is associated.[1]

"The veins are replacement deposits; there is little material filling open cavities, most of the ore replacing the rock-forming minerals on both sides of narrow fissures. The original hornblende of the rock is replaced by aggregates of biotite foils, which also invade the feldspars; the feldspar substance is replaced from small cracks by pyrrhotite and chalcopyrite, forming a characteristic network which, by gradual extension, finally replaces the whole rock. . . . The sulphides do not as a whole have crystalline outlines, though in some places the grains show crystal faces. The secondary character of the sulphides is further shown by narrow linings of quartz, chlorite, or biotite. The feldspar substance, generally clouded by interpositions of biotite, muscovite, etc., usually presents a narrow, clear rim adjoining the sulphides." (Lindgren.)

19. *Copper-silver Veins, Peruvian Type.* — Veins in augite, porphyrite, or the inclosing limestones, containing rich silver sulphides and antimonial or arsenical sulphides of silver and copper. The character changes with depth to gray copper (tetrahedrite) with pyrite, blende and some galena in a barite gangue, with carbonates and zeolites, but changing with further depth to a quartz gangue. Examples occur at Huancavelica, Peru, in the Atacama region of Chile, especially at Chanarcillo; Pulacayo, Asiento, and Ubinoin, Bolivia; and at Smeinorgorsk, Siberia.[2]

20. *Cupriferous Gold Veins, Chile Type.* — The veins of this type are an extreme variation of the tourmaline copper veins, though they are classed in the table as hot-spring deposits. They consist of a gangue of quartz and tourmaline containing pyrite, chalcopyrite, and other copper sulphides, and often free gold. The lodes occur with acid eruptive rocks, especially granite. Examples occur in Chile, Australia, Norway,[3] etc.

IV. Deposits formed by Atmospheric Waters

The superficial deposits grouped under this heading have, with one great exception, little or no economic value, and their character is apparent. The deep deposits due to underground water may include the

[1] E. Kirby, "Ore Deposits of Rossland," *Journal* Canadian Mining Institute, vol. vii, p. 14; R. Brock, *ibid.* (discussion). W. Lindgren, "Genesis of Ore Deposits." American Institute of Mining Engineers, p. 565.

[2] R. Beck, *op. cit.*, pp. 281–282.

[3] R. Beck, *op. cit.*, p. 306.

conglomerate and amygdaloid beds of Michigan, according to Van Hise, and the genetically similar but mostly unworkable deposits of basic eruptive rocks in many parts of the world.

V. Metamorphic Deposits

The deposits due to serpentinization of a basic rock with accompanying segregation of the copper include the deposits of central Italy, whose genesis is alleged to be igneous by some writers. The minute copper contents of diabase and of diorite are sometimes segregated by solution at the same time as and as part of the process of metamorphism which transforms the igneous rocks into amphibolite. This does not mean that all the copper deposits in or associated with amphibolites have this origin.

This class includes deposits that are similar to contact deposits in mineral composition; they are composed chiefly of old impregnations or old sedimentary deposits, perhaps enriched by metasomatic processes, and very different from the deposits formed by the solutions of hydrothermal waters.[1] The second class is the common pyrite deposit, for convenience called the Huelva type.

"Orebodies lenticular in shape; repeated, and connected by impregnated zones; composed mainly of pyrite, less commonly of pyrrhotite, and with chalcopyrite."[2]

Orebodies of irregularly lenticular shape, lying parallel with the foliation of schists or slates, form a well-marked type of copper deposit of world-wide distribution, including many of the great copper deposits of the world. In general, the copper occurs associated with sulphide of iron. This type is the *Kieslager* of the Germans, the copper deposit being merely a copper-rich form. Indeed, most pyrite deposits of this type contain copper ores in their upper levels, and most copper deposits of this type become lean and pass into pyrite at greater or less depth.

General Characters. — The bulk of the deposit consists ordinarily of pyrite (FeS_2), with chalcopyrite as a common and characteristic associate. In many cases pyrite is replaced by magnetic pyrite (pyrrhotite). The accessory minerals are galena and zinc-blende, usually in small, rarely in large, amounts, and frequently segregated, not uniformly distributed.

Garnet, actinolite, and amphibole are common, but biotite, epidote, and pyroxene occur in various examples. Quartz is common, calcite

[1] *Loc. cit.*, "Genesis," etc., p. 731.

[2] Kemp, "The Deposits of Copper Ores at Ducktown, Tenn." *Trans.* Am. Inst. Min. Eng., vol. xxx, p. 244.

scanty but common. Zoisite is a characteristic mineral at Ducktown, Sulitelma (Mous Petre), etc. Fumarolic minerals, tourmaline, fluorite, chondrodite, occur in Vermont and foreign localities. The shape is usually a long, thin lens, or a succession of lenses simulating a bed. Inasmuch as the so-called bedding is schistosity, due to pressure, obscuring or hiding the true and rarely parallel original bedding, the long-accepted belief of sedimentary deposition is slowly passing away. Where, as at Capelton, Que., and Mount Sicker, B.C., the slaty or schistose rocks are recognizable under the microscope as igneous rocks, no sedimentary origin is supposable. At Huelva, Spain, one wall is commonly porphyry and the other a schist.

The Huelva type, as commonly defined, embraces deposits now known to have very different structural and mineralogical features. The class is misleading but convenient, as it groups together deposits whose form and general composition are similar, and which are found in crystalline rocks. The Spanish and Norwegian deposits lie at or along igneous contacts. The Tasmanian deposits are on fault planes bringing together dissimilar rocks. The Ducktown deposits are in altered sedimentary rocks, but cross the schistosity and are veins; and the Ore Knob (N.C.) and Gossan Lead (Va.) examples are veins occupying fault planes. The deposits of Shasta county, California, are in shear zones in rhyolites of Triassic age. The Besshi (Japan) deposits are in graphitic schists, and the Vancouver deposits are in similar rocks. Pyrite or pyrrhotite is the dominant sulphide, and quartz the common gangue, though at Vancouver and in the Shasta county deposits it is barite. These notes are sufficient to show that the class is only useful as indicating form and rock texture, not genesis.

VI. Sedimentary Deposits

The Mansfeld, Germany, copper deposits are generally regarded as an example of a sedimentary ore deposit. The ore occurs in a thin bed of bituminous marl, that is a normal part of the sedimentary series. There is some doubt as to the correctness of this conclusion.

PART II

DESCRIPTIONS OF THE PRINCIPAL COPPER MINES OF THE WORLD

VIII

THE COPPER MINES OF EUROPE

The copper mines of Europe have been worked since the days of the Roman Empire, and though many of the deposits are exhausted and abandoned, the great productive mines of today are also the oldest. The mines of Spain were among the earliest opened, and appear to have been worked for many centuries by the Romans. The Mansfeld (Germany) deposit has been in practically continuous operation for a thousand years, and has, according to recent estimates, an equally long life ahead of it. A few other notable examples of the longevity of some of the copper mines of Europe could be given, though most of the many deposits of that continent have been worked out.

European copper deposits are of much general interest, not only because they include a great variety of types, but because they have been studied and records kept of their character and development for centuries. Hence many deposits of present industrial insignificance are of scientific importance because they afford the data by which to judge of the nature and character of similar deposits in other parts of the world.

The prospect of an increased production from European mines is not bright. The Norwegian deposits of low-grade pyrite ores are expected to show a considerable increase. The eastern countries, Bulgaria, Roumania, and Servia, whose industrial development was long retarded by political conditions, are said to contain valuable deposits, worked to shallow depths, but idle for centuries. Other old mines in Greece and Italy, some of them now being reopened, may prove profitable, but no safe prediction can be made.

In presenting a summarized description of these mining districts the deposits are grouped by countries and the latter arranged in alphabetical order, hence not in the order of their importance.

Austria-Hungary

Austria, though a copper producer for centuries, has now only a few producing mines, and the yearly output is small (2,744,000 lb. for 1906). The mines are in Bohemia, the northwestern state of the empire, separated from Germany by the Erzgebirge. Near Graslitz, a 15-ft. bed of argillaceous slate, formerly mined but idle for many years past, was reopened in 1901 at the Klingenthal mine.

Northeastern Bohemia is underlain for extensive areas by the sandstones and slates of the Rothliegende formations, containing beds impregnated with copper ores. The ores are not confined to a particular bed, but occur at variable horizons at Wernersdorf, Oberkalna, Kosinetz, and many other localities. At Wernersdorf the ores in the unweathered state consist of finely divided copper glance found in the clay slate roof and floor of a bed of conglomerate. Concretions of pyrite with a core of glance are common, varying up to 4 or even 5 in. across.

The Mitterberg copper mines near Werfen, in the Austrian Tyrol, have yielded about 600 tons of copper a year for a considerable period. They are situated in the Tyrolean Alps, 15 miles from Bischofshofer on the Austrian state railway between Innsbruck and Salzburg. The veins outcrop at an elevation of 5500 ft., the mountains rising 2500 ft. or so higher. The ores occur in veins in Silurian clay slate. Three parallel lodes are worked, and four levels opened. The ore is chalcopyrite, with small amounts of pyrite, arsenopyrite, and nickel, with traces of gold and silver, in a quartz gangue carrying ankerite, calcite, dolomite, and siderite. The ore shoots are composed of compact stringers, 1 in. to 30 in. wide, in a low grade, but payable lode filling. The occurrence is shown in Fig. 15, the inclosing rock being Silurian slates and schists. The orebodies appear arranged in echelon in the different lodes, both copper ore and siderite forming lenticular masses inclined at an oblique angle to the wall. The ore averages 3 per cent copper. The output for 1905 was 23,000 tons, picked and concentrated to 7000 tons, yielding 615 tons metallic copper. The reserves are large, and the lodes well defined.[1]

At Kitzhübel, also in the Austrian Tyrol, the Kupferbergbau Kupferplätte mine is working a flat lode composed of chalcopyrite in pyrite with gangue of siderite and quartz, found in the Silurian slate series. The deposit is a quartzose variation of the spathic copper veins (Kams-

[1] Edward Walker, "The Mitterberg Copper Mine." *Engineering and Mining Journal*, March 17, 1906, p. 507.

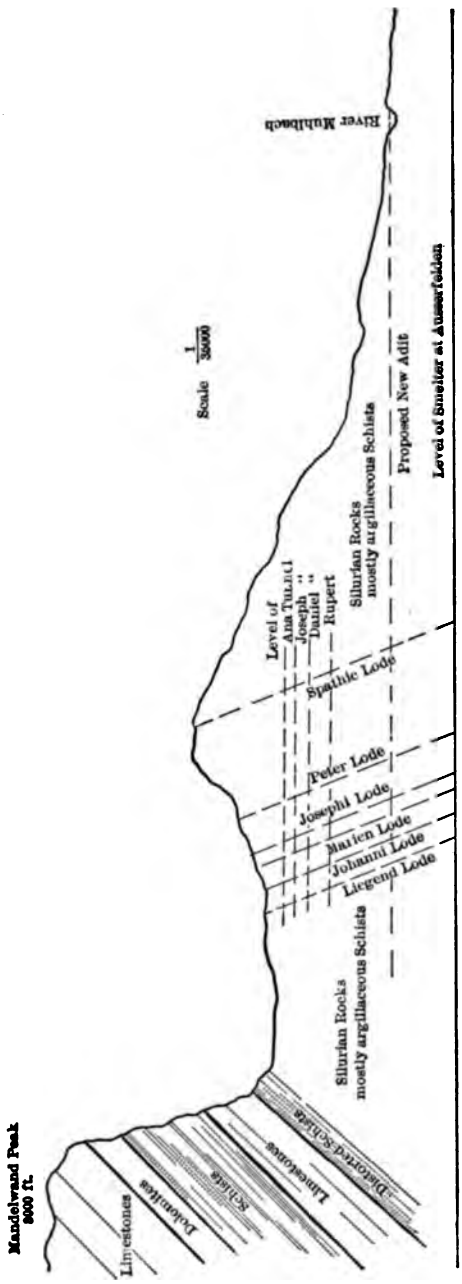


FIG. 15.—GEOLOGICAL FORMATION OF MITTERBERG COPPER MINES

dorf type). The fissures have a maximum thickness of 13 ft. and are filled by ore with slate fragments. The chief workings are at Schattberg, in the Kupferplätte, and at the Kelchalpe; the deposits were extensively worked many years ago.

At Brixlegg, in the same region, the production for 1903 was 225 metric tons of copper, with 600 kilos of silver and 5 kilos of gold.

Hungary. — The copper mines of the Banat, in Hungary, are now only worked for iron ore. They are contact deposits, of irregular form and distribution, found in garnet-amphibole rocks, produced from impure Tertiary limestones by intrusive masses of monzonite. These copper ores carry gold and are traversed by gold quartz veins.

The Schmoellnitz mines of upper Hungary, though unimportant producers, derive their ores from peculiar deposits. The ore consists of narrow layers of bornite and nests of cupriferous pyrite, in lenticular bodies of banded pyrite (Huelva type), and impregnations of a bed of gray slate, a member of a formation of black carbonaceous slate. Three of these impregnations, called "strikes," extend to considerable depths, differing from the stocks of banded pyrite, which, though large, wedge out in depth. The greatest lens was 400 ft. long and 137 ft. thick, but gave out at a depth of 465 ft.

In northern Hungary, at Altgebirge and Herrengrund, north of Neuschl, there are veins of the spathic copper class, in mica schist (Pfeifer vein), and interlaminated with the Triassic graywackes. The filling consists of quartz, barite, siderite, ankerite, chalcopyrite, and tetrahedrite. Veins of the same character, but with cinnabar as well, are found at Kotterbach, Szlovinka, and Göllnitz, in the crystalline schists of the Gömör Alps.

The pyrite stock of New Moldova in the Banat is located at the contact between dacite and garnet rocks. The largest orebody is 130 ft. thick, 1300 ft. long, and 426 ft. in vertical extent. The lenses wedge out in depth, but the impregnated beds are persistent. The ore is banded, and at the margins of the orebody grades into the barren rock.

The deposits of the Banat have been fully and repeatedly described by various geologists. Their chief importance at present is as producers of iron ores. The deposits are adjacent to igneous intrusions and show distinctive contact metamorphic characters, though they differ somewhat in each of the districts of the range. At Szaska rich copper ores occur associated with tremolite in nests, and chalcopyrite and pyrite occur with iron ores. At Oravicza-Coiklova it has been observed that different rocks yield different ores. Thus the dacite-limestone contact is characterized by pyrite and chalcopyrite; the dacite-mica schist contact by the absence of ore, and the syenite-hornstone schist contact by chalcopyrite, arsenopyrite, and tetrahedrite. The garnet limestone belts are most richly mineralized and carry chalcopyrite, tetrahedrite, arsenopyrite, blende, galena, and pyrite. Fissures, mostly small, in dacite contain chalcopyrite or pyrite.

At Moravicza-Dognacska there is a contact aureole about the intrusive rocks, in which garnet-tremolite-black pyroxene rocks appear, the garnet and magnetite being of synchronous age, as seen in thin sections. Copper and various other metals occur as sulphides in these rocks.[1]

Bosnia

Bosnia contains copper veins with tetrahedrite in a barite gangue sometimes containing cinnabar. It yielded 114 tons of copper in 1901, but the geological conditions are unknown.

Bulgaria

Copper-bearing veins occur at Cara Bair, about 3½ miles west of the port of Bourgas, and at Soulon-Dere and Cara Tepe, all in the same district. The veins yield rich ores (40 per cent), but have only been mined to a depth of 100 ft. The yield for 1904 is estimated at 400 tons.[2]

France

There are no producing copper mines in France, the old and famous mines of Chessy and other lesser ones being exhausted. The copper now produced in that country comes from the pyrite mines, the largest and most productive deposit being that of St. Bel, northwest of Lyons. The ore forms lenses inclosed in hornblendic and chloritic schists, and grouped in a series or range 1⅛ miles long. The extensive deposit of the south field is one of the great pyritic masses of the world, being 1968 ft. long, and having a maximum thickness of 140 ft. at a depth of 544 ft. It consists of massive, very dense, fine-grained pyrite, with a very little quartz. Eruptive rocks are lacking, as at Ducktown, Tenn. Numerous fault slips occur between the ore and schists. Other orebodies contain chalcopyrite and blende, and the cupriferous portions are highly silicious and banded.

At Cap Garonne, near Toulon, there are quartz conglomerates of

[1] See Beck, *op. cit.*, p. 617. [2] *Echo des Mines*, April 15, 1905.

Hanover.................... 55 tons as a by-product from two works.
Westphalia............... 47,718 tons from three copper works and eighteen others.
Hesse-Nassau............... 257 tons from two copper works and three others.
Rhine provinces........... 6,132 tons from one copper smeltery.
Communion Unterharz...... 15,216 tons from one place.

Mansfeld. — This mine has been worked since 1199. Five hundred years ago it produced 1000 tons of metal a year; it now yields fifteen times that amount, and employs 13,000 men.

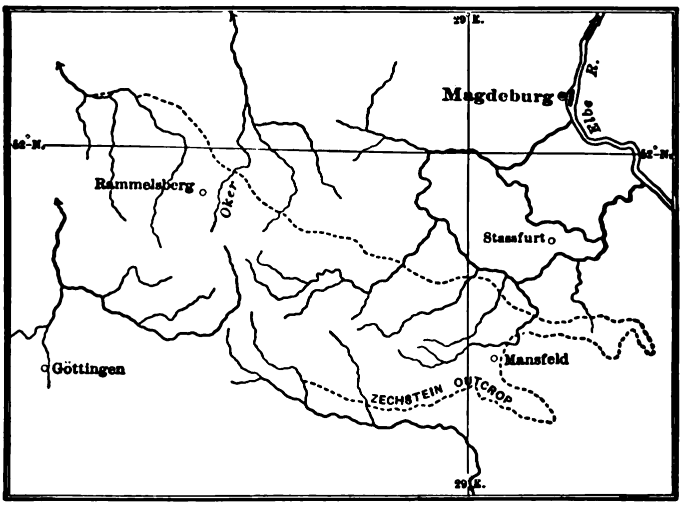


FIG. 17. — MAP SHOWING BOUNDARY OF MANSFELD COPPER BASIN, GERMANY

The ore is a blackish, bituminous, marly shale of Permian age, forming a bed but 15 to 18 in. thick in a conformable series of red shales and sandstones. This bed is an important but extremely thin member of the Zechstein series, which forms a fairly regular basin about 120 miles from east to west, and 60 to 90 miles wide, in central Germany. The copper shale underlies about 193 sq. miles, but the workings are confined to the northern and western sides of the basin, where the copper shale lies almost horizontally for a distance of 14 miles. At this place the whole bed carries copper, but only the lower 2½ to 5 in. of it is rich enough to work. A thickness of 16 to 20 in. of rock is, however, removed, and the bed is worked by the longwall system, the miners lying on their sides while at work.

The ore, which carries 2 to 3 per cent copper and 1.63 oz. silver per ton, is mostly a *speise,* the metallic minerals occurring in dust-like particles, showing metallic luster on fracture. The ore is golden yellow from chalcopyrite, violet to copper red from bornite, or rarely steely lustered from glance. Pyrite sometimes colors the ore grayish yellow, and galena

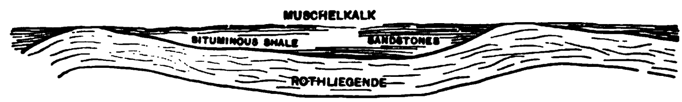


FIG. 18 — SECTION ACROSS MANSFELD COPPER SHALE BASIN. (DE LAUNAY)

a leaden gray. These minerals also occur at times in veinlets and bunches. The ore is very hard, ringing when struck, and carries many fossils, those of ganoid fishes being especially abundant.

The average composition is as follows:

Silica	29.22 to 38.42	Copper	2.00 to 2.93
Alumina	11.28 to 15.93	Sulphur	2.15 to 4.97
Lime	10.93 to 14.39	Bitumen (ignition)	9.89 to 17.21
Magnesia	2.25 to 4.53	Carbon dioxide	7.02 to 13.51
Iron	0.85 to 3.31		

Zinc, lead, manganese, nickel, and cobalt are present in traces.

The seam, though persistent, is, in this area, much broken by fault veins, often barren, but sometimes rich in cobalt and nickel, as well as copper. Moreover, the copper shale is often richer than usual close

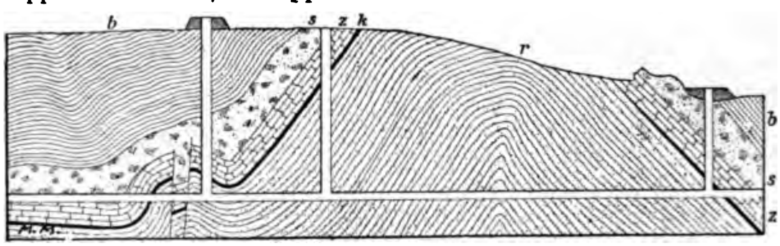


FIG. 19. — SECTION SHOWING FOLDING AND FAULTING OF COPPER BEARING BED AT MANSFELD, GERMANY

to these fissures. There is an observable decrease of copper with that of the bitumen.[1] Figure 19 shows the dislocations at the Tiefthal district, Mansfeld. The rocks inclosing this bed are largely red in color.

The same Permian series contains copper at Frankenburg, but in an

[1] R. Beck, *op. cit.*, p. 515.

entirely different bed. The red-brown Permian sandstones contain various layers of white limestone concretions carrying plant remains, replaced by copper glance and occasionally by native silver, pyrite, chalcopyrite, more rarely tetrahedrite, bornite, and proustite. The ore occurs in nests; it averages 0.572 per cent copper and 0.0013 per cent silver.

At Bieber the ore occurs in a bituminous marl and the underlying schist, but is workable only near ore veins.

Origin of the Ore. — The Mansfeld copper shale bed has been long regarded as the typical example of a sedimentary ore deposit, formed by chemical precipitation of the metallic matter of sea-water, with accompanying deposition of clayey sediment in closed moraine basins. The metals, supposedly present as sulphates, were accompanied by alkaline sulphates, the latter being decomposed by decaying organic matter, developing hydrogen sulphide, which brought down the metallic sulphides.

A very ingenious modification of the sedimentary theory of genesis has lately been proposed by Horning; viz. that highly concentrated mother liquors formed from sea-water in shallow lagoons, such as the natural "salt pans" of the Caspian Sea, induced deep-seated metamorphic (oxidizing) alteration in all the rocks to which they gained access; that this oxidation produced a precipitation of iron oxide, and the saline liquors gradually took up various heavy metals from diabase, crystalline schists, or preëxisting mineral veins. These saline pools were then suddenly buried by marine gravels and sediments due to subsidence and flooding. This brought about a precipitation of the metalliferous material by decomposing marine organisms and the settling of flocculent sediments. This metalliferous material was sorted out and distributed by the flood waters.

This ingenious theory depends for its acceptance upon the contradiction of the facts stated by previous observers, that the distribution of the copper was influenced by relative permeability and by the amount of bitumen (8 per cent to 30 per cent) in the rock. If this hypothesis has merit it should be supported by the facts observable today in the shallow bays of the Caspian Sea, by observations in the Great Salt Lake region, where borings have been made for oil, and by deep borings made in the neighborhood of rock salt deposits and the brines of petroleum wells; but neither in the localities cited nor in the case of the German salt deposits is this confirmatory evidence found, and the facts in the Mansfeld basin itself seem as inconsistent with the acceptance of this [illegible] to be with the [illegible]

[illegible] — [illegible] second largest copper district of [illegible] mountain on the [illegible] of the city of Goslar. The [illegible] in an overturned fold, as [illegible] occurs in slate, not in crystalline [illegible] The ore bed is composed of [illegible] ore whose layers are [illegible] so that all of the [illegible] in the ore. A [illegible] the hanging-wall [illegible] ore bed. The [illegible] pronounced in the footwall of the [illegible] extending into the ore. [illegible] known as Fimmer's [illegible] as an overthrust [illegible] the orebody shows [illegible] ft. thick, except [illegible] across. The [illegible] ft. long.

of pyrite and galena. (4) Fine-grained mixture of sulphide ores, the so-called lead ores, known as brown ores when blende predominates, or gray ores when barite is in excess. The ores are dense and compact, except in the later formed transverse veinlets, which show well-crystallized minerals. The ore is supposed to have been formed by replacement of an impure limestone having bands of rather coarser dark-colored limestone in it, and the banded structure is the result of the replacement of this material of varying character.[1]

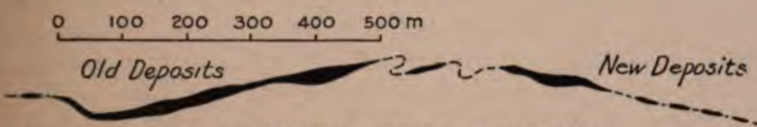


FIG. 21. — PLAN OF RAMMELSBERG OREBODY, GERMANY. (AFTER KLOCKMANN)

In *Saxony* there are cupriferous quartz veins in the Schneeberg district, the most noted being the old Koenig, David, and St. Michaelis.

GREAT BRITAIN AND IRELAND

The copper mines of the United Kingdom are found in Cornwall, Devon, Wales, and Ireland. The present production of copper, about 500 tons, comes from Cornwall as a by-product of tin mining. The other districts are idle; but their reopening is occasionally discussed, and a few notes are therefore given.

Cornwall and Devon. — The deposits of this region are practically all tin-copper deposits, which yielded large amounts of copper for a century. The ores occur in veins traversing granitic masses and the baked sedimentary rocks about them.

The copper-tin lodes of Cornwall and Devon, the pyritic copper deposits of Ireland, and the veins of Cumberland gave Great Britain fame as a copper producer for a century or more. The only deposits now worked are in Cornwall, where future mining in some cases must depend for its success upon a utilization of all three metals, tin, tungsten, and copper, found in the ore.

The copper production of Cornwall, formerly very important, is now reduced to about 500 tons per year. The region is interesting because of the peculiar nature of the deposits and the association of tin ores in depth. The most productive mines of the region are the Dolcoath and Devon Consols, now worked for tin, the copper content

[1] See Beck, *op. cit.*, p. 479, for full references and discussion.

being mostly disregarded. In the near future other mines, if again worked, will endeavor to recover tungsten, tin, and copper.

The region is one of Paleozoic sediments and greenstone sheets, cut and altered by granite, with associated quartz porphyry dikes. The veins parallel the dikes, as shown in Fig. 22. The copper ores occur at a higher horizon than the tin, and hence the veins in altered slates are apt to be copper-bearing, and in granite are tin-bearing. They are cut and displaced by cross and counter lodes. Figure 22 shows the association of elvans (quartz-porphyry dikes) and veins.

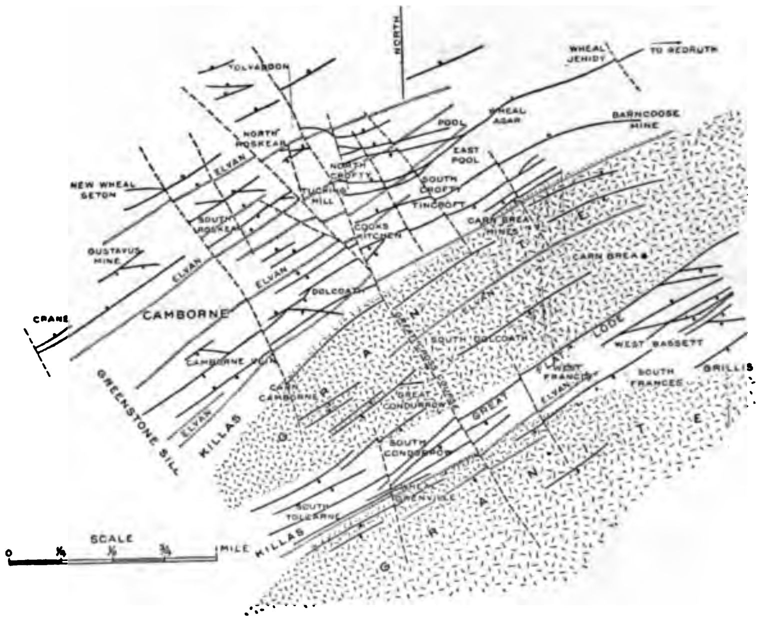


FIG. 22. — PLAN OF TIN-COPPER VEINS, CAMBORNE, CORNWALL, ENGLAND

The copper occurs as chalcopyrite with quartz gangue. Tourmaline, fluorspar, chlorite, "clay," pyrite, and cassiterite occur as associates. The tin-copper ores occur in impregnated and replaced rock on the sides of narrow veins or leaders, but the copper ores do not form the carbonas, great pendant masses of ore, seen at St. Ives. The lodes all afford good examples of secondary enrichments.

The Dolcoath mine, now 2786 ft. deep, in the Camborne district, was formerly the most important mine, but is now worked for tin.

Lode formation was the latest phase of igneous activity. No part of a lode is absolutely barren, but the best ore occurs in shoots that pitch east.

"All the lodes are tin-copper, belong to one system of fracture, and the ores were deposited from a common solution, cassiterite concentrated mainly in one place, the more soluble copper going to greater heights, and being less restricted in occurrence."

The cross veins dividing the ore veins fault 20 per cent of the latter, throw 50 per cent to right and 30 per cent to the left side, or 67 per cent to greater and 13 per cent to lesser angle. About one-third of the

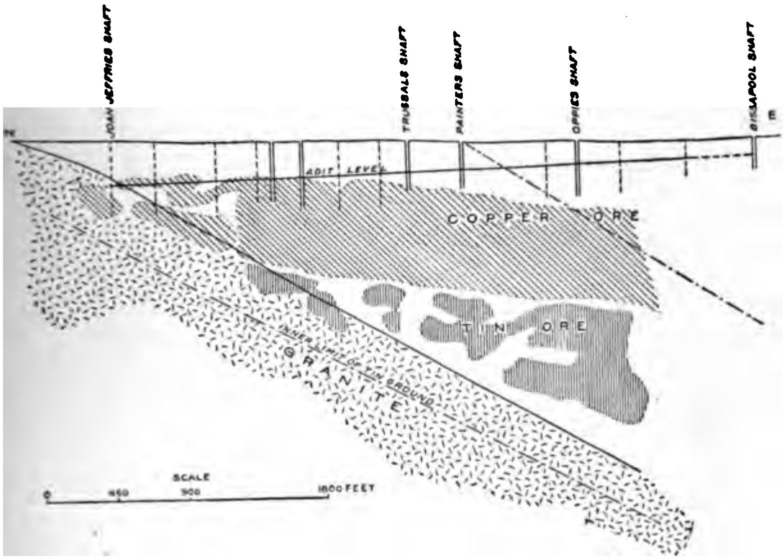


FIG. 23.—CROSS-SECTION OF TIN-COPPER VEIN, CAMBORNE

faults observed in the tin-copper mines are overthrust displacements. Warm saline (chloridic) waters occur in the deep workings of the Camborne mines.

Cheshire contains numerous deposits of oxidized copper ores disseminated in sandstone, the copper contents being about 1½ per cent.

Wales. — Wales possesses a number of old, long idle veins formerly yielding copper ores. The best known is at Parys Mountain, Anglesea Island. The ores occur in quartz veins lying between "felsite" dikes and Silurian slates. The Carreg-y-doll lode is 5 to 60 ft. wide, and carries bunches of copper pyrite and vugs of extraordinary size and beauty. Copper also occurs impregnating the feldspar rock.

Ireland. — The old copper mines of County Wicklow, Ireland, are of interest mainly because of the oft-mooted possibility of their being reopened. Copper mining in this region practically ceased about 1840, but the mines were worked for pyrite until supplanted by the cheaper Spanish product. The copper occurs as chalcopyrite in veinlets and cupriferous pyrite in lodes and parallel associated lenses in Silurian slates, altered by contact action, near granite masses. The veins conform nearly to the strike of the rocks, but invariably cross them horizontally and vertically at a small angle. The Ovoca belt is 6 miles long. The Tigroney and West Cronebane deposits consist of a main lode of pyrite [1] cut and thrown by numerous faults and accompanied by lenticular hanging-wall bodies of chalcopyrite intercalated in the slates, and sometimes in the lode itself. The lenses are small and are sometimes connected by strings and branches. The main lode varies from 36 to 50 ft. in thickness. The lodes sometimes fray out in strike or are cut off by feldspar porphyry. The veins are pre-Carboniferous. A copper lode occurs at Carrigat, south of Bantry Bay, County Cork,[2] and another at Knock Mahon, County Waterford.

Italy

Italy has an annual output of about 3,000 tons of copper, derived from 16 mines located in the following districts: Grosseto or Florence district, south of Leghorn; Liguria, west of Genoa; and the Massa Marittima, or Turin region.

The deposits present considerable variety of geologic character, the metal occurring in bedded deposits of pyrite in metamorphic slates, in stocks in gabbros and serpentines, and in quartz veins. The deposits in serpentine are the most important source of copper in Italy, though this type is rare elsewhere. The Tuscan mines produce the bulk of the output, though their grade averages but 3 per cent.[3]

Grosseto District. — The mines of this district are the largest and best-known copper deposits of Italy. They lie in the Tuscan Apennines, between Genoa and the head waters of the Tiber river.

The Monte Catini is the most important mine; and the company of this name, owning this and other mines, is the largest producer of the country. The mine is in the Grosseto district, about 12 miles south-

[1] A. T. Phillips, "A Treatise on Ore Deposits," revised by Henry Louis, 1904, fig. 8, p. 309.
[2] Phillips, *loc. cit.*, p. 312.
[3] *Mining Journal* (London), vol. 79, February 17, 1906, p. 223.

east of Leghorn, in the hills between the low coastal plain and the Etruscan Apennines. The orebodies occur in a great laccolitic mass of gabbroic and dioritic rock intruded in Eocene limestones. This rock is exceedingly basic in the vicinity of the orebodies, being a lherzolite.[1] It forms an irregular upright stock, more or less serpentinized, and close to the orebody is altered to a crushed and broken softened serpentine. The ore forms three irregularly branching, stock-like masses of considerable size, but of irregular distribution, and confined wholly to the more highly altered and crushed portions of the serpentine. The most extensive orebody is an irregular, many-armed stock found at the base of the eruptive and near the contact with the limestones. Lotti regards the deposits as magmatic segregations; but the constant association with serpentine, both in these deposits and those of Liguria and

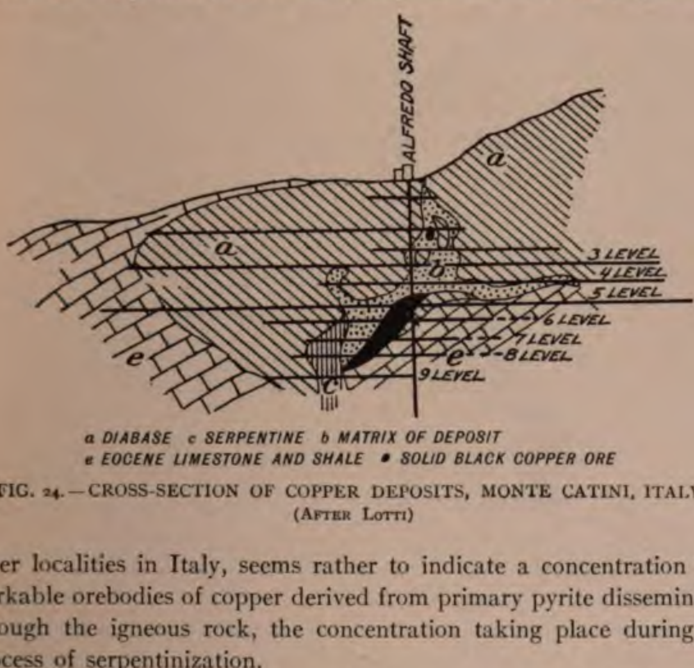


FIG. 24.—CROSS-SECTION OF COPPER DEPOSITS, MONTE CATINI, ITALY. (AFTER LOTTI)

other localities in Italy, seems rather to indicate a concentration into workable orebodies of copper derived from primary pyrite disseminated through the igneous rock, the concentration taking place during the process of serpentinization.

Massa Marittima.—The second important copper district of the country is that of Massa Marittima. The district of this name lies a few miles from San Vicenza, a station on the Mediterranean Railway, and situated about 24 miles northeast of the island of Elba.

The ores occur in fissure veins along fault planes. The wall rocks

[1] An enstatite-augite-peridotite.

are much altered, either by silicification with deposition of chalcopyri and pyrite or a segregation of epidote in places, or else a complete meta morphism to an epidote-pyroxene rock, the alteration extending farthe into the hanging wall than into the foot.

The veins are of post-Eocene age and are largely of the cupriferou quartz vein type, the Boccheggiano being the most important. Othe veins carry mixed sulphides of copper, lead, and zinc. Besides the vein there are irregular orebodies resulting from the replacement of th limestones along bedding planes separating that rock from shale.

The Fenice Massetano, Capanne Vecchie, Serrabottini, Sud, an Guardione are all veins of the pyrite-blende-galena class. The Capann Vecchie Company, owning several properties in the district, is the secon largest producer in the country.

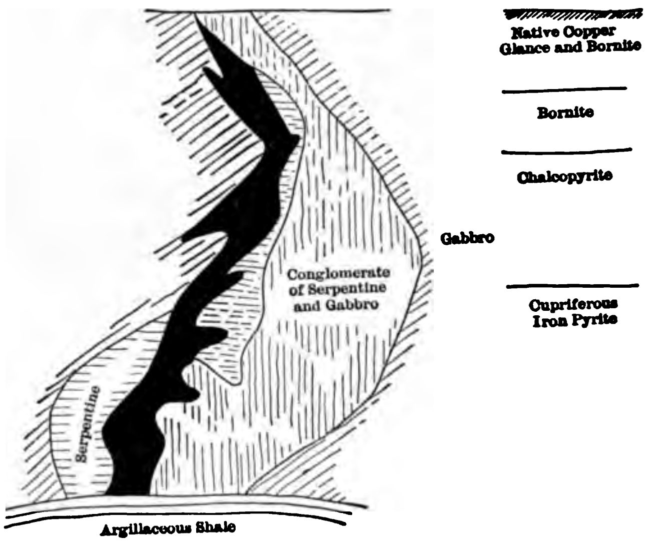


FIG. 25.—VERTICAL SECTION OF OREBODY, MONTE CATINI, ITALY

At the Massetano deposit the ore comes mainly from the Fenice vein, which is worked in several mines. The vein has a thickness of from 6 ft. to 100 ft., dips at 45 deg. to the east, and cuts through Eocene shales and limestones. It is worked for a distance of over half a mile. The ore consists of chalcopyrite in a quartz gangue, with a little pyrite as an accessory mineral. The ores average about 3 per cent copper, but sometimes run up to as high as 11 per cent, and are concentrated before smelting.

The Boccheggiano vein, in the same district as the last, is worked by the Monte Catini Company. This vein is peculiar in the fact that its northern portion is a quartzose copper vein, while its southern part consists of a complex mixture of pyrite and blende, with a little galena and copper.[1]

The vein runs due north and south from the Farmulla valley to that of the Merse, thence southeast and southwest. The dip is 45 to 50 deg. east, the mean thickness 13 to 16 ft., and the richest streak is near the hanging.

The vein occupies a fault between micaceous Permian shales and Eocene limestones and shales, the latter forming the hanging wall. The filling consists of quartz carrying pyrite and chalcopyrite, with a little bismuthinite and hematite. In places the filling consists of slate fragments cemented together by ore. Epidote occurs abundantly in certain layers, and extends along cross fractures into the country rock for a distance of 150 ft. or more. The ore is chalcopyrite, generally in finely granular compact masses, more rarely as druses. Pyrite is common as an associate and in masses, and in isolated crystals in the wall rock. Galena, blende, and arsenical marcasite occur, and veinlets occur in the limestone, of black, gray, lustrous tetrahedrite, carrying 6.62 per cent Ag, 31 per cent Cu, 7 per cent Zn. The ores carry 3 to 11 per cent of copper, and are remarkable for the presence of .04 of 1 per cent tin. The deep workings of the mine are very troublesome on account of a large hot spring with a temperature of 105 deg. F.

Temporino.—In this same part of Tuscany, about 17 miles north-north-

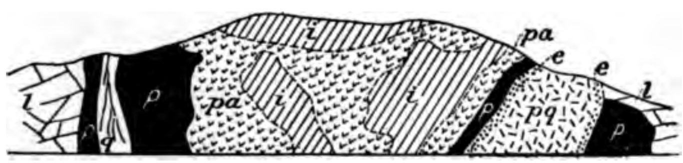


FIG. 26.—CROSS-SECTION OF TEMPORINO VEIN, CAMPIGLIA MARITTIMA (LOTTI)

east of the island of Elba, there is a very remarkable deposit known as the Temporino vein. The country consists of marbleized Liassic limestone, in part covered by rhyolite, and cut by a very peculiar dike of rhyolite porphyry, constituting the ore deposit. This dike is 65 ft. wide, and

[1] E. Tacconi, "Note Mineraria sul Giacimento Cuprifero de Boccheggiano." *Transactions* Reale Accademia deo Lincei, 1904, vol. 13, pp. 337-341.

consists of iolite-bearing rhyolite porphyry, with a central band of augite porphyry. The ore, which occurs along the boundary between the dike and the limestone, consists of augite, in part a dark green lime-manganese augite, in part a greenish-gray or red manganese-lime augite. The augite forms radial balls permeated by ilvaite with chalcopyrite, pyrite, and small amounts of galena, sphalerite, and some arsenopyrite, together with quartz and calcite, either as the cores of the augite balls or as particles between the fibers. Veinlets of augite penetrate the limestone. The deposit has many of the characteristics of a contact deposit. The mines were worked in Etruscan times and during the days of the Medici, and have recently been reopened by an English company.

Ligurian District.—A number of important mines occur in the Alps of the Ligurian district, northwest of Genoa. The deposits are all connected with basic igneous rocks, but, unlike the deposits of Monte Catini, the chalcopyrite cements fragments of crushed, hard serpentine. The deposits of the Alps are described by Lotti[1] as nodular segregations from gabbroic rocks. The chief mine of the Ligurian region is the Libiola, owned by an English company. It produces considerable pyrite, as well as copper ore, and has been profitably worked for some years. The deposit, like that of Monte Catini, is regarded by many writers as due to segregation of copper from gabbroic rocks during the serpentinization of the material.

The production for 1902 was 4564 tons of 4.75 per cent ore, with 22,727 tons of pyrite.

In addition to these copper mines proper there is considerable production from properties of mixed sulphides, as, for example, that of Messina, in which a vein carrying antimony and lead yields some copper. Tetrahedrite ores also occur at Avanza.[2]

Sardinia. — The copper deposits near Bena de Padru occur on the slopes of Monte Tramento, about one-third of a mile from the high road which connects Ozieri with the railway station of Fraigas. The ores are in a belt of clay slates alternating with limonite schists and underlain by granulite, the copper ores occurring near the contact. There are three "distinct veins consisting of strings of lenticles, largely of chrysocolla, with associated quartz and calcite." The chrysocolla changes in depth to chalcopyrite. Copper ores occur at many other localities in Sardinia, but not in payable quantity. The present deposit

[1] "E deposito metalliferi di Itali."

[2] A short description of these mines, prepared by the Corpo Reale delle Miniere for the Paris Exposition, was printed in 1900.

is not now productive, but is being developed. An interesting feature of some of the ore lenticles is a chocolate-colored mineral resembling limonite, but consisting of 34.5 per cent cupric oxide and 38 per cent of iron oxides.[1]

Corsica. — There are a dozen or more small copper mines in Corsica. They lie in a district 80 km. long and 30 km. wide, crossed by three railway lines. The deposits resemble those of Monte Catini, occurring in serpentinized basic rocks intrusive in limestone.[2]

NORWAY

The chief copper mines of Norway yield pyritic ores similar to those of the Spanish deposits. Copper deposits of other kinds are found, but their product is quite small, or the deposits are no longer worked.

The great deposits of low-grade cupriferous pyrite are found scattered along the old and planed-down mountain range which forms the backbone of the country, extending from 59 to 70 deg. north latitude. There are four distinct districts; viz. the islands of south Norway (west coast); Grimeli, or central coast; Trondhjem region; and the Sulitelma district in Nordland, north of the arctic circle. The first-named district embraces the mines of Vigsnäs, Bömmelo, and Varaldsö. This and the Grimeli district are of little present importance. The Trondhjem region embraces mines of the well-known Röros and Meraker districts. The Sulitelma properties are the largest producers of the kingdom.

The deposits of all these localities are similar in character, occurrence, and composition. They are typically lenticular in shape, are conformably intercalated in crystalline schists made from the Dekono (Silurian) strata, and lie alongside of intrusive bodies of saussurite gabbro, or its associated soda granite. The orebodies consist of iron pyrite with disseminated particles of chalcopyrite and quartz. The lenticular masses vary from a few feet up to 65 ft. in thickness. They have no great horizontal extent (width), but extend downward to great depths, forming great columns or "rods," i.e. long, narrow masses of relatively small lenticular cross-section, but of great length.

According to Vogt,[3] who has carefully studied the deposits, they belong to the Huelva type, a conclusion disputed by Klockmann.[4] According to the former, they were formed by mineralizing solutions derived

[1] See abstract in *Transactions* Institution of Mining Engineers (London), 1904.
[2] R. Beck, *op. cit.*, p. 48.
[3] "Genesis of Ore Deposits," Am. Institute of Mining Engineers, 1901, p. 651.
[4] *Zeit. für praktische Geologie*, 1904.

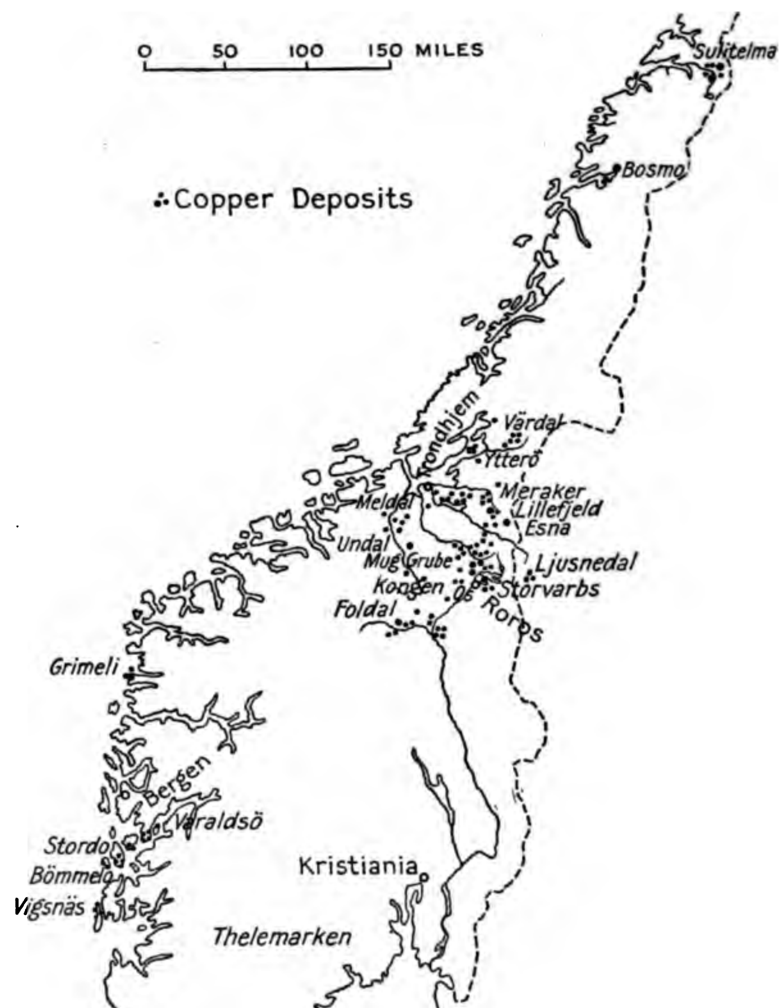


FIG. 27.—MAP SHOWING DISTRIBUTION OF COPPER DEPOSITS OF NORWAY (VOGT)

from or generated by the gabbro intrusions, depositing the ores in cavities formed along slipping planes of the schists during their metamorphism. This conclusion is based upon the facts that the orebodies, though intercalated in the schists, do sometimes cut across the foliation, and included fragments of schist appear in the ore. Both the rock and ore are oftentimes strongly folded and compressed, sometimes with fine crinkling. Slickensides are common in all the deposits, and pyrite appears to have sometimes been segregated during folding. The invariable association of gabbro (or its peculiar accompanying soda granite) and orebody is hard to explain on any other hypothesis than the one advanced by Vogt; viz. eruptive after effects (highly heated vapors), the ore deposition preceding the final consolidation of the granitic magma in depth, as shown by dikes cutting across the orebodies. The gabbros are undeniably eruptives in which the basic feldspar is replaced by saussurite (zoisite and albite), with diallage replaced by hornblende (var. smarogdite), actinolite, chlorite, garnet, and rutile.

The ores have a gangue of quartz, which sometimes increases in amount and takes the place of the copper pyrite. With the quartz there is a less quantity of other minerals, viz. hornblende, mica, diopside, and garnet, with accessory amounts of feldspar, epidote, titanite, chlorite, talc, and fluorspar. Besides the tin and copper pyrite mentioned, blende, pyrrhotite, galena, and arsenopyrite sometimes occur in small amounts.

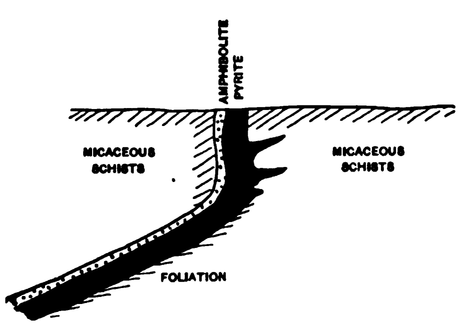


FIG. 28.—VERTICAL SECTION KONGEN MINE, NORWAY. (DE LAUNAY)

The Trondhjem region contains the Röros and Meraker districts; the Mug, Storvarbs, and Kongen mines being in the first, and the Meraker and Foldal mines in the second district named.

The deposit worked at the Mug mines is typical of all the rest. The pyrite occurs interbanded in a flat or slightly tilted phyllite. The mass is 328 ft. to 500 ft. wide, only 3 ft. to 10 ft. thick, but is proved for some 424 ft. in length. The production for 1903 was 740 tons copper and 13,808 tons of pyrite. The Storvarbs deposit is similar and is somewhat larger. The orebody sometimes shows banding parallel to the wall, and passes into country rock by splitting up into many streaks and patches of pyrite in the schist, a feature also observed at the Mug mine.

The Röros district produced 1,383,077 lb. of copper in 1903.

The Sulitelma district lies north of the arctic circle. The mine of this name is owned by the Tharsis Company, whose Spanish property is nearly worked out. It was only opened in 1887, and is now the largest producer of the kingdom. The ore carries 3.75 to 4.5 per cent copper. It is smelted raw, the material charged carrying 4.7 per cent Cu, 32 to 34 per cent S, with 34 to 36 per cent of iron, and 2 to 4 per cent alumina. The matte is bessemerized in converters having a basic lining. The mine produced 6,225,856 lb. copper in 1905; 1,001,056 lb. was reduced at the company's smelter, the rest being in the ore exported.[1]

Kristiania. — The copper deposits near Kristiania, though numerous, are small and of slight economic importance, but are interesting scientifically, being the type of the well-known Kristiania or contact type of copper deposit. They "occur in the majority of cases exactly on or very close to the contact of syenitic rocks and Silurian limestones and slates, along which they are found in great numbers and of irregular form." The ores are sometimes banded parallel to the bedding and occur only in the sedimentary rock. They consist of chalcopyrite, with magnetite, galena, hematite, sphalerite, and rarely bismuth and arsenical and antimonical sulphides in an aggregate of garnet amphibole, pyroxene mica, epidote, vesuvianite, scapolite, quartz, calcite, fluorite, and axinite. According to Vogt, the ores are due to magmatic exhalations — so-called eruptive after actions — blown into (and metasomatically replacing) the adjacent rocks of whatever character. The evidence appears to support this hypothesis, not only for them, but for similar deposits in other countries; but Vogt's conclusions[2] that the pyrite deposits of Röros, Sulitelma, etc., are of similar origin is not yet fully accepted.

The tourmaline veins of Thelemarken, South Norway, are ladder veins in granite dikes, cutting quartzitic slate at Näsmark, or as contact veins on the borders of a granite dike at Moberg.

At Svartdel copper is found with gold and tourmaline in quartz-mica diorite, changed on the fissure walls to greisen, the deposit thus resembling a transition form between tin and copper veins, as recognized in the Chilean copper deposits.

[1] Stevens, "Copper Handbook," 1906.

[2] "Problems in Geology of Ore Deposits," *Transactions* American Institute of Mining Engineers, vol. xxxi, 1901, p. 140; "Genesis of Ore Deposits," 1901, p. 650.

Russia

Russia consumes about 20,000 tons of copper annually, of which one-half is produced within the empire. Three regions contain practically all the workable deposits, viz.: (1) The Ural; (2) Transcaucasia; (3) central Siberian provinces. Finland is still a small producer, and there are old mines in Poland. In each region the supply comes from a few large mines. Three mines furnish half of the Russian production, two of the three being in the Ural (Perm).

The total copper production of Russia in 1903 was 5546 metric tons, of which the Ural region supplied 2868; the Caucasus, 2165; Finland, 275; the Altai, 228; and the Kirghiz steppes, 9. The total production for 1906 was 10,490 tons, the relative proportions being somewhat altered.

The great copper-producing points of the empire are the Vissk and the Bogoslov works of the Ural, and the Palakent and Kedabeg smelters of the Caucasus. The celebrated rich ores of the Kirghiz deposits have been hampered by want of fuel, but have recently been vigorously worked. The Altai region is holding its own, and the Finnish deposits are being developed.

Transcaucasia.[1] — About 44 per cent of the copper produced in Russia comes from Transcaucasia, that portion of the empire which stretches southward from the Caucasus, between the Black and Caspian seas, to the frontiers of Turkey and Persia. In 1902 this region produced 106,718 tons of ore, yielding 3438 tons of copper. Railways now run from Tiflis to Karas and Alexandropol to Erivan.

The three copper-producing centers of the region are Kedabeg, 26½ miles from Dalliar station, on the Tiflis-Baku Railroad; Allah-Verdi, on the railway from Tiflis to Alexandropol; and, thirdly, the Evlach or Zanghezur district, 130 miles from Evlach, on the first-named railway.

Kedabeg. — Kedabeg is the largest producer of Transcaucasia, and has the largest smelting plant. It lies 26½ miles from, and 450 ft. above, Dalliar, the nearest railroad station on the Baku line. The deposits are found in the side of Copper Mountain, Mio Dagh, 5922 ft. high, occurring as lenticular masses found in a belt of quartz-porphyry 3500 ft. long and 1700 ft. wide, with diorite to the south and diabase porphyry on the west.

The latter rock occurs in dikes cutting the quartz-porphyry, and also

[1] P. Micou, "Le Cuivre en Transcaucasia: Notes de Voyage." *Ann. des Mines*, 1904, ser. 10, vol. vi, pp. 5–54; 4 figs. and plate.

est station on the Transcaspian railway line. The ore occurs in quartz veins carrying chalcopyrite, with associated bornite, tetrahedrite, pyrite, and rarely native copper. Small values in gold and silver occur.

There are 20 veins varying from 7 in. to 4 ft. in width and clustered, in a range running northwest and southeast, through dark green andesite and black diabase. Fault fissures cut the veins and country rock.

The old workings are primitive, narrow adits running 100 to 300 ft. into the hillside, and both ore and water were carried in leather bags.

The copper ore occurs in quartz veins. The ores consist of chalcopyrite and bornite, tetrahedrite and pyrite, with accessory blende and galena, the usual oxide ores and native copper being present. Old shafts 130 ft. deep attest the energy of the ancient miners, when ores below 15 per cent were not workable.

The ore occurs in northwest and southeast quartz veins cutting andesite, and in crush zones or breccias between syenites and diorites, the ores carrying copper glance, galena, and sphalerite. The veins have a proved length of 700 ft. in depth. The output for 1900 was 800 tons of copper. Only 7 per cent ore or better is treated, and this is smelted at Sounthsky for $5.80 a ton. Mining costs $8.08 per ton.

The Allah-Verdi district lies in a very mountainous tract about 50 miles south of Tiflis. The ore occurs in pockets in fractured dacite and quartz andesite. It is pyritic and treated by modified pyrite smelting. There are three deposits: Akthala, Allah-Verdi, and Chambuk. An enrichment near gypsum masses is noted. Galena rich in gold and silver occurs near the uppermost part of the first-named deposit. The mines, though ancient, have but recently been reopened.

Ural District. — The chief copper mines of Russia are in the Perm and Orenburg governments, west of the Ural Mountains, where the reddish sandstone series, called Permian, from the province, is copper-bearing for some 300 miles westward from the base of the mountains. The district contains many old and nearly worked-out mines, like that of Miednorudiansk, famous for the great masses of malachite worked up into vases and works of art for the imperial palaces.

The Ural region is the most highly mineralized section of Russia; it contains several large producing mines as well as many now nearly exhausted. The character and relations of the Frolov ore deposit are shown in Fig. 30.

On the west side of the Ural Mountains copper deposits occur as bunches in Permian rocks, mainly in the governments of Perm, Viatka, Kasan, Orenburg, Ufa, and Samara. The ores are oxidized and low-grade [illegible] 3 per cent.

The Miednorudiansk mine, in the Nishni Tagilsk district, is not far from the well-known Visokaya Gora. The ores are oxidized, and occur in veins in slates and limestones of Devonian age, but cut by diorite. The famous pockets of rich oxidized ores, mainly malachite, pass in depth into pyrite and chalcopyrite.[1]

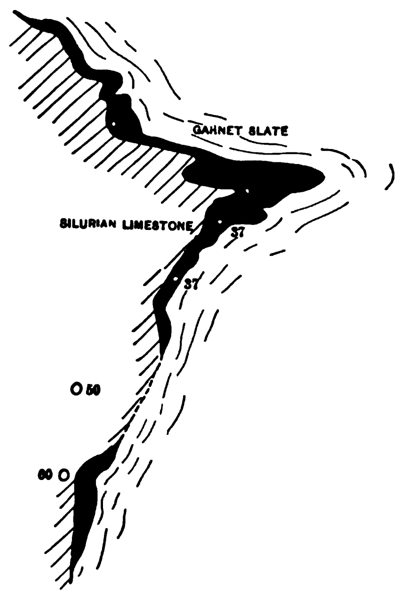


FIG. 30.—VERTICAL SECTION OF THE FROLOV MINE

Bogoslovsk. — The deposits of the east side of the Ural range are associated with or near iron deposits lying in crystalline schists. The deposits are usually found between porphyries or diorite and a contact rock known as venissa, composed of augite and garnet; or the lenses occur between limestone and eruptive rock, as, for example, that of Bogoslovsk. At this locality the ore occurs in lenticular shoots in contact metamorphic rocks, at the contact between limestones and dioritic rocks. The orebodies are cut and faulted by porphyry dikes (see Fig. 31). The main orebody is 656 ft. long. The ore carries 2.5 to 3 per cent copper, or, when sorted, 4.5 per cent copper. The porphyry ore is a crushed and altered rock, impregnated with chalcopyrite, magnetite, and cupriferous pyrite, with a little quartz and calcite. The deposits run parallel to the Ural range, with a northeast

[1] Krusch, *Zeit. für praktische Geologie*, 1897, p. 277.

est station on the Transcaspian [illegible] mines embrace three properties
veins carrying chalcopyrite, wi[illegible], Perm. The production in
and rarely native copper. Sm

There are 20 veins varying [illegible] and other Ural provinces contain
in a range running northwest [illegible] occurrence to those of the Mans-
and black diabase. Fault [illegible] and Orenburg, and farther south

The old workings are pri[illegible] deposits in sandstone, especially
into the hillside, and both o[illegible] these beds, but also in fine dust-

The copper ore occurs in [illegible] and nodules. The ores consist of
rite and bornite, tetrahedrite [illegible] the plant remains, where it is
lena, the usual oxide ores a[illegible] and other sulphides occur. The dis-
130 ft. deep attest the en
15 per cent were not work

The ore occurs in northw
and in crush zones or b
carrying copper glance, g
length of 700 ft. in depth
Only 7 per cent ore or bett
for $5.80 a ton. Mining

The Allah-Verdi dist
miles south of Tiflis.
and quartz andesite.
ing. There are three
An enrichment near g
silver occurs near the
mines, though ancient

Ural District. — T
and Orenburg govern
reddish sandstone se
bearing for some 30
The district contains
of Miednorudiansk
up into vases and

The Ural regio
contains several
hausted. Th
shown in Fig

On the w
bunches in F
Kasan, O
grade, n

[illegible] BOGOSLOVSK MINE. RACHETT SHAFT
[illegible] CAUSE ON LEFT

[illegible] to several beds but a few inches to a
[illegible] is very irregular. There are from two
[illegible] the other. The ores average 3 per cent.
[illegible] at Kargalinsk, 24 miles from the city of
[illegible] found in the Donetz area, east of Bach-
[illegible] by red clays. The ores, though poor,
[illegible][2]

[illegible] east of Lake Baikal, contains several

[illegible] Gumeshevsk, now abandoned, see Beck, *op. cit.*, fairly large copper properties; viz. Pavovski, Tsarevo, Alexandrov, and Yuspenssky.

According to E. Nelson Pell, the Kirghiz steppes of southwest Siberia contain vast stores of copper in the region south of the Transsiberian Railway, between the Urals and the Altai range.

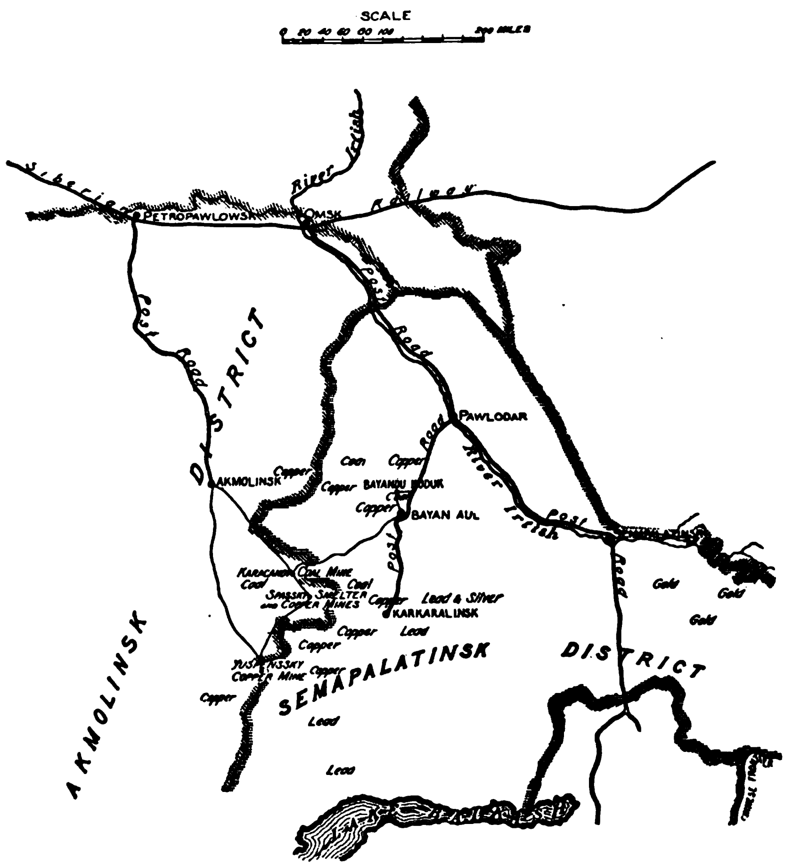


FIG. 32.—MAP SHOWING LOCATION OF THE SPASSKY MINE AND OTHER COPPER DEPOSITS OF THE AKMOLINSK DISTRICT, SIBERIA

The copper occurs in both igneous and sedimentary rocks, but mostly near igneous contacts, or in igneous rocks along dikes and faults, or in sedimentary rocks on faults and bedding planes. Outcrops occur in extraordinary number, usually defined by the absence of the normal grass and the presence of "copper flowers." Impregnation deposits

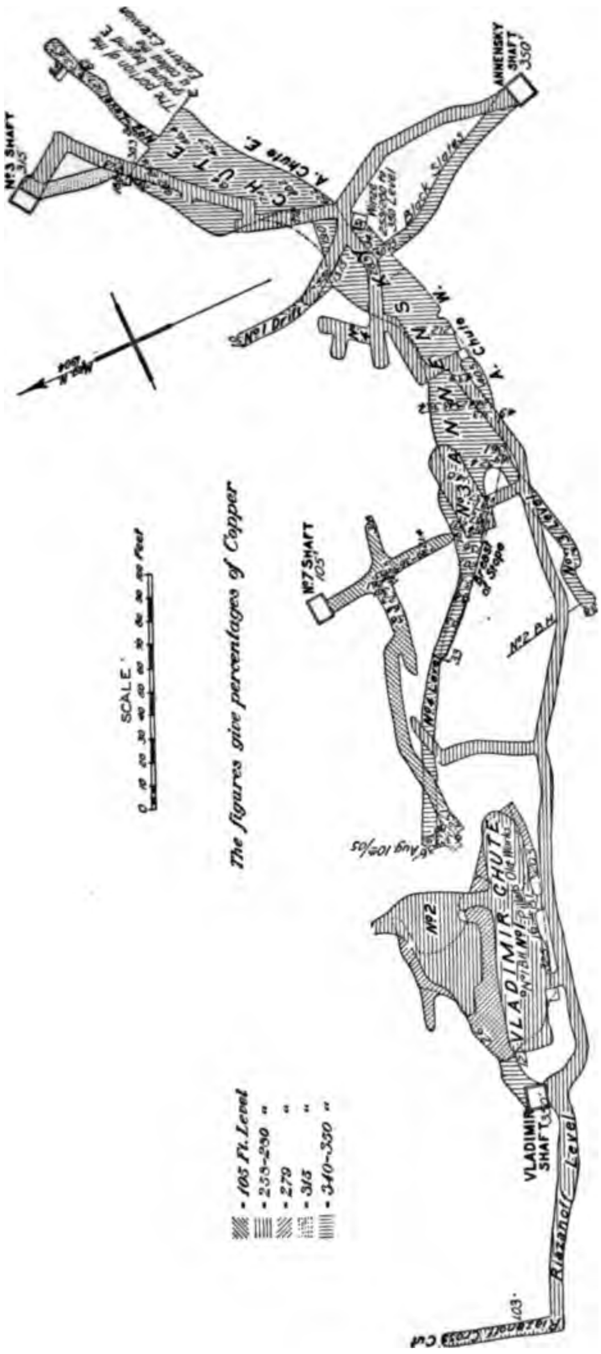
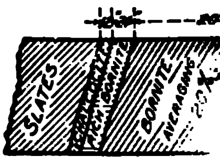


FIG. 34.—PLAN OF WORKINGS OF SPASSKY MINE

are very large and low-gra[illegible]	[illegible]4 to 11.2 per cent
One shaft sunk by Pell g[illegible]	[illegible] to 4.2 per cent
ores averaging 4 per ce[illegible]	[illegible]8 to 1.1 per cent
The Spassky Copper	[illegible]0 to 3.0 per cent
most important copper m[illegible]	[illegible]0 to 50.4 per cent
on the low, undulating	[illegible]7 to 11.6 per cent
miles from the Siberia[illegible]	[illegible]8 to 6.0 per cent
insk. The ore occurs [illegible]	[illegible]7.5 to 97.4 per cent

around a shallow valle[illegible] [illegible] is 99.5 fine, and carries $25
with a low ridge of [illegible]
grit merges into sandst[illegible] [illegible] are known in the Altai region.
stone, on the footwal[illegible] [illegible] 24 ft. thick, the ore being
wall. This slate ha[illegible]
shown in Fig. 33 th[illegible] [illegible] of the Chida river there is a
[illegible] found in amygdaloidal mela-
[illegible] and masses of native copper
[illegible] associated with the metal.[1]



[illegible]INLAND

FIG. 33.—CROSS-S[illegible] deposits located on the north shore
[illegible] have been worked for fifty years or more.
per cent on the foo[illegible] [illegible] and coarse red granite. Several
in a sandstone gan[illegible] worked contains chalcopyrite in a
Vladimir, and is [illegible] thick, and mined for a length of 1½
is 250 ft. long an[illegible] at 40 to 50 deg. At the east end
horses of slate, [illegible] sections or beds, in which the ore
sandstone and [illegible] A transverse section shows the footwall
350 ft. and wor[illegible] to consist of skarn, with finely divided
occurs. In [illegible] This is overlain by a (b) bed 28 in.
1500 tons of [illegible] in turn by (c) a 3-ft. bed of barren schist;
1905, the re[illegible] thick. These beds are underlain and
As, howeve[illegible] mile west of a point where this section
than 6 ft. wid[illegible] segregated in bunches as large as one's fist,
the orebodi[illegible] minerals.
and gray cop[illegible]

POLAND

barite occurs
mine yields [illegible] to work the old lead and copper mines
of the ore [illegible] which were exploited one hundred

[illegible] vol. ix, 1901, p. 391.

years ago, with fair results. Attempts to work the old copper mines at Chenciny also have recently been made. The ore is carbonate of copper, impure malachite, and azurite, from which, by the use of sulphuric acid, sulphate of copper is obtained.

Servia

The copper deposits of Rebelj and Wis are in northwestern Servia, southwest of Valjero, in the basin of the Yablonica river, which enters the Kolubara. The cupriferous belt runs northwest and southeast for 15 miles along the north slope of the Povljen Mountain range. This range consists of Mesozoic sedimentaries intruded by masses of serpentinized igneous rocks.

FIG. 35.—CROSS-SECTION OF COPPER DEPOSIT, REBELJ, SERVIA. (Firks)

The Rebelj deposit occurs in a sill or sheet of serpentine, intercalated in pale gray argillaceous limestone, with calcite veinlets. This serpentine is 197 ft. thick and outcrops for one-third of a mile. The rock is

FIG. 36.—CROSS-SECTION OF COPPER DEPOSIT, WIS, SERVIA. (Firks)

much altered, much slickensided, and is rich in magnetite. The ore forms lenticular masses up to 53 × 98 ft., consisting of a core of crystalline pyrite, with chalcopyrite, calcite, and serpentine gangue, and carrying 5 per cent copper. The outer shell of the lens consists of copper and iron pyrite, with a little serpentine, this ore carrying 15 per cent copper. Both orebody and serpentine show limonite gossan, carrying various oxidized ores.

The Wis deposit is in a dike of serpentine intrusive in Triassic limestone, with a border band of diabasic friction breccia cemented by calcite lying between the serpentine and limestone. The ore occurs very near the breccia, forming irregular lumps, sometimes a ton in weight, of chalcopyrite with accessory pyrite and serpentine. The ore originated as concentrations during the serpentinization of the olivine-bearing mother rock.

Similar deposits occur at Radanovci, Wuinovatz, and Staninareta.[1]

Spain

Huelva District. — The copper district of the province of Huelva, southwest Spain, is not only the fourth largest producer in the world

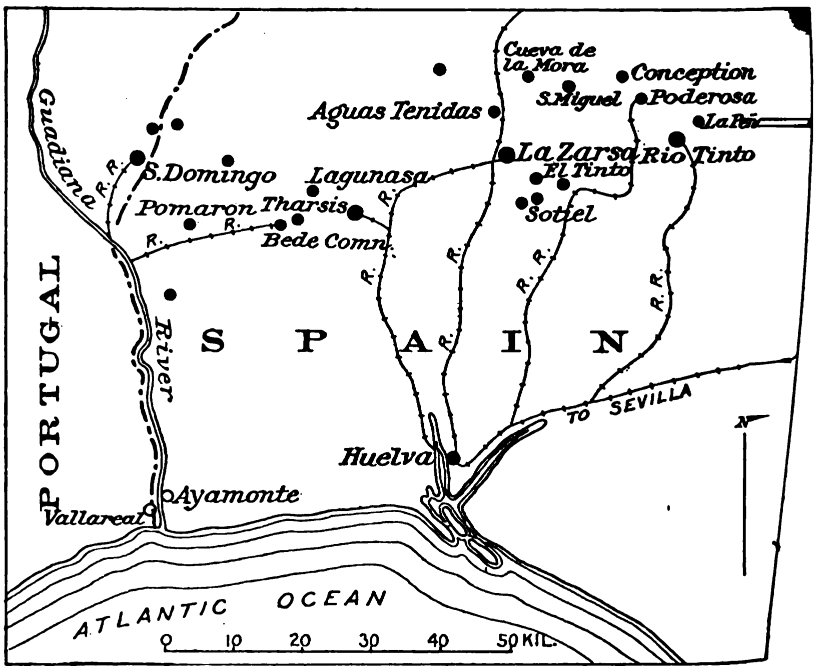


FIG. 37. — INDEX MAP OF HUELVA COPPER FIELD, SPAIN

[1] W. von Firks, *Zeit. für praktische Geologie*, vol. ix, 1901, pp. 321–322.

but furnishes the pyrite from which most of the sulphuric acid of Great Britain and several other countries is obtained. The district borders on the Atlantic coast between Cadiz and the Portuguese boundary, the deposits occurring in a zone 80 miles long and 12 miles wide, extending eastward from the San Domingo mine (Mason and Barry) in Portugal. With this single exception all the important mines are in Spanish territory, and most of them ship their ores over railway lines to the port of Huelva, which lies 27 to 49 miles distant.

The copper belt is a broken, hilly country lying back of a flat coastal plain. The district is underlain by Paleozoic rocks, with numerous exposures of igneous intrusives. A mantle of Tertiary sediments overlaps and conceals these rocks toward the coast, while northward Silurian and Archean rocks appear. The prevailing rocks are coarse clay slates of Carboniferous (Culm) age, with graywacke, phyllite, and lesser bands of limestone and quartzite. The igneous rocks occur in east to west alinement, clearly marking general lines of fracture and intrusion. The prevailing forms are green quartz porphyry, feldspar, porphyrite, and diabase. The geologic map indicates the existence of a broad underlying batholitic mass of granitic rock.

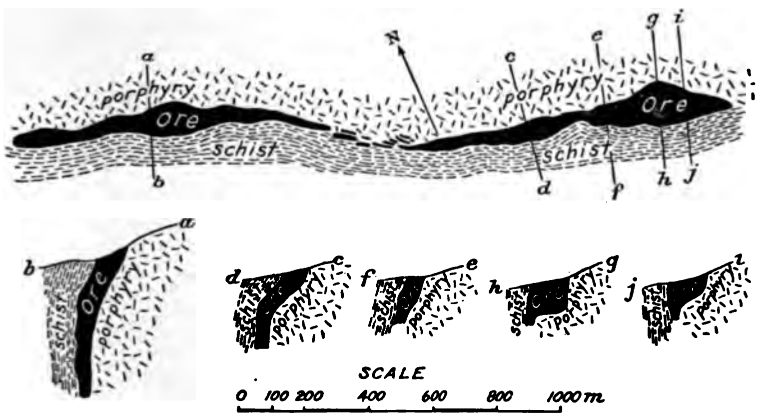


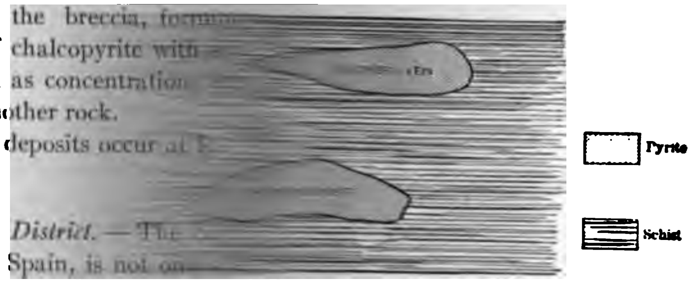
FIG. 38.—CROSS-SECTION OF OREBODIES, RIO TINTO, SPAIN. (GONZALES)

The region is well mineralized, and manganese, zinc, and other ores are mined at various places in the copper belt, but occur entirely independent of the copper deposits.

The copper deposits of Huelva show the following general characters: they occur only at or close to the contact with porphyry intrusions, and crystalline pyrite, with chalcopyri[illegible] numerous igneous intrusions. carrying 5 per cent copper. Th[illegible] form both horizontally and and iron pyrite, with a little s[illegible] at shallow depths. The copper. Both orebody and se[illegible]: rarely slivers of country various oxidized ores. [illegible] are connected by clusters

The Wis deposit is in a d[illegible] deposits. limestone, with a border band [illegible] orebodies worthy of note, their calcite lying between the ser[illegible] to 100,000 sq. yd. They vary very near the breccia, form[illegible] weight, of chalcopyrite with [illegible] originated as concentration[illegible] bearing mother rock.

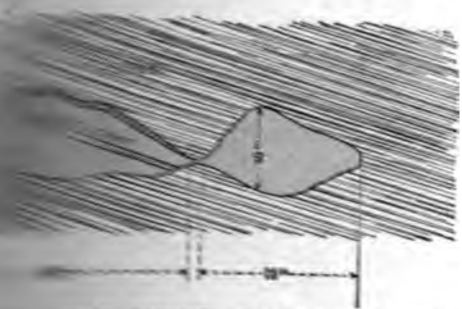
Similar deposits occur at F[illegible]



Huelva District. — The [illegible] southwest Spain, is not on[illegible]

[illegible] MASS. SCALE, [illegible] (GONZALES)

[illegible] largest, that of the south lode of [illegible] thick, and mined to a depth of [illegible] shape and geological position. As a [illegible] cross-section, as shown by the



[illegible] DEPOSITS. SCALE, [illegible] (GONZALES)

[illegible] horizontal plan the ends often wedge out [illegible] along the line of the lode extended. [illegible] to long narrow ones. [illegible] variety in occurrence, being found in

FIG.

W.

both the Carboniferous and the Silurian areas and in various rocks. They are sometimes inclosed in altered diabase; and where the lens lies across the foliation, or so-called bedding of the rocks, the inclosed slivers and partings are parallel to the country, not the deposit walls. Moreover, the Chaparita orebody shows the base of the orebody in porphyrite, while the outcrop consists of two bands separated by slate.

The ore is sometimes banded parallel to the stratification. It consists of pyrite with branching stringers of chalcopyrite and copper glance. According to Jones,[1] the copper is mainly present as Cu_2S; and it is this

FIG. 41.—CROSS-SECTION OF RIO TINTO OREBODY, SHOWING DECREASE OF COPPER IN DEPTH. (VOGT)

fact that makes the ore so readily oxidizable, so that the treatment followed is simple washing with water, resulting in the production of cement copper, the washed ore retaining its shape, though somewhat friable, and being shipped for acid manufacture. The ore carries only traces of gold, but has 1 to $1\frac{1}{4}$ oz. of silver per ton.

FIG. 42.—PLAN OF EAST EXTREMITY OF OREBODY, SAN DOMINGO, PORTUGAL. SCALE, $\frac{1}{800}$. (GONZALES)

All the ores show a gradual decrease in the copper content from the surface downward. In the Tharsis and San Domingo mines the ores are

[1] *Transactions* American Institute of Mining Engineers, vol. xxxv, p. 3.

now too low-grade to be valuable for copper, but are mined for pyrite only. This decrease is due to secondary concentrations, deposited as films and veinlets of chalcocite, or chalcopyrite in the upper parts of the deposits.

The origin of the Huelva deposits has long been a matter of dispute. They were formerly regarded as of sedimentary origin. Vogt, who has studied and described them, considers them a result of contact metamorphism. According to Klockmann, the orebodies are conformably intercalated in Culm slates, with associated eruptive sills of quartz and quartz-free porphyry, porphyrite, diabase, and amygdaloid tuffs, all conformably intercalated. He regards conflicting observations by other investigators as inaccurate and untrue. The hypothesis of concretionary segregation within a plastic clay slate saturated with pyrite-forming materials, and initiated and accompanied by pyrite precipitation, is advanced. The igneous rocks, regarded as due to submarine eruptions, are the supposed "ore-bringers." [1]

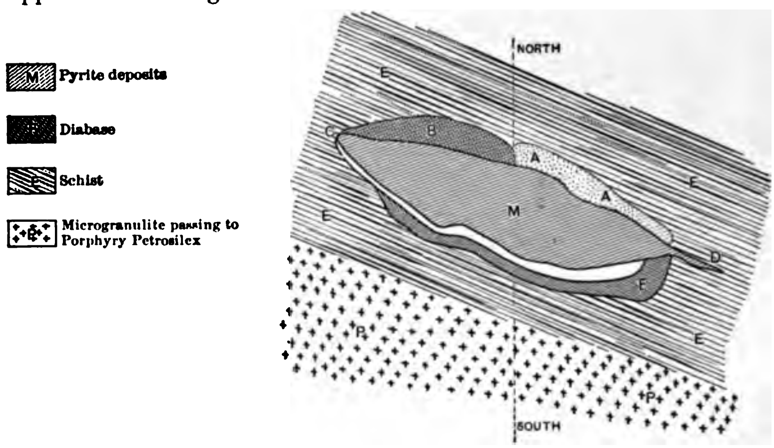


FIG. 43. — PLAN OF SAN DOMINGO PYRITE DEPOSIT, PORTUGAL. (GONZALES)

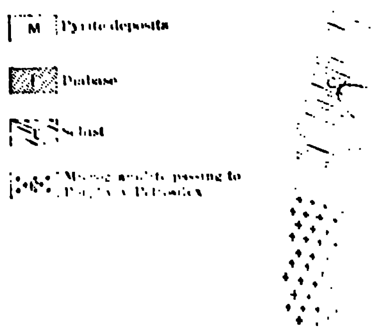
Gregory,[2] the latest writer, concludes that the deposits are not normal contact metamorphic deposits, because (1) the ore was clearly formed long after the adjacent igneous rocks; (2) some deposits occur entirely in slate and not along contacts; (3) when on contacts, it appears to be due to faulting. The evidence favors the idea of metasomatic replacement.

[1] F. Klockmann, *Zeit. für praktische Geologie*, vol. x, 1902, pp. 113–115.

[2] "The Mt. Lyell Deposits." *Transactions* Australasian Institute of Mining Engineers, 1905.

now too low grade to be valuable for cop only. This decrease is due to second films and veinlets of chalcocite, or cha the deposits.

The origin of the Huelva deposits They were formerly regarded as of sed studied and described them, consider morphism. According to Klockma intercalated in Culm slates, with asso quartz free porphyry, porphyrite, conformably intercalated. He rega investigators as inaccurate and untr segregation within a plastic clay sl terials, and initiated and accompani The igneous rocks, regarded as supposed "ore bringers."[1]



PLAN OF SAN DOMIN

Gregory of the latest write contact metamorphic depo along after the adjacent ign slate and not along to be due to faulting. T replacement.

[1] Klockmann, *Zeit. für* ...
... Lyell Depo ...

copper to sulphide

near the Guadix similar to Minorca.

a, Spain, are develop an average thickness

ant amount of copper, industry of the country. The chief mine of the rked since 1288 by the seventeenth century it sup es stamped with the value, ins.

acers, viz.: Helsingborg, in ne district; Kafvelorps, in

mportant mine of Sweden, is and lake of Falun. According mainly a fine-grained biotite medium-grained, gray gneisses tes, hornblende schists, granular rnblende rock).

has produced 35,000,000 lb. ton is used for making sulphate Tinto, being an irregular mass at the outcrop and 650 ft. long, carries 2 to 5 per cent copper and

micaceous quartzite, that forms a Besides quartz grains it contains magnetite, actinolite, and antho of the quartzite, which are sharply varying amounts of disseminated

... de España, 1902, ser. ii, vol. 5.

... Geology of Falu Mine).

es sphalerite. This
f the entire output,
The ore is irregularly
y lustered quartzites.
. more or less rounded
pyrite, as in a cement.
show no definite genetic
ssible combinations, and
quartz grains and abun-
fine veinlets have entered
ning quartz grains. Hence,
. the present sulphides existed
e was formed by metamorphic
e formations occurring at times
a result of subsequent pressure.
rocks of that locality.
nated quartzite, stock-like bodies
re mined. The largest of these
lar body, extending downward for
over the north circle 600 feet in
show that the stock has completely
sibility of an overlapping stock at the
f the stocks (***blötmalm***) averages 2 to 3
ks themselves are in reality nothing but
ated with pyrite, but the impregnation
l ore both in quantity and quality. For
m one to the other are found in the so-
which on examination under the microscope
ingredients of the gray quartzite. The com-
pyrite masses varies. Quartzose, calcareous,
es are distinguished in the stocks. The quartz
ly predominant. It is essentially a granular-
iron pyrite and quartz, with accessory cordierite,
ite, copper pyrite, magnetic pyrite, zinc-blende,
galena. It is especially significant that the iron
in small crystals as inclusions, not only in the
in the cordierite and anthophyllite. The other
are apt to constitute the filling between the grains of
the "soft ore," too, breccia-like structures are not
ich case fragments of pyrite are inclosed by quartz,

and fell to the bottom this organic ma... ...ns of iron pyrite. Hence and it also sank. ...at gave rise to the breccia, ...e ore took place.

The Granada deposit, 15½ miles ... road, is in a mountain district 1000 ... ...alcspar. It is evidently a but not as yet worked.[1] ...eposits, such as occur in this

The Cerro Muriano mines, 10 mi... ...e ore, on the other hand, ing a large mass of 4 per cent co... ...n of the granular limestone of 3½ ft.

... a large and rather irregular

Though Sweden produces ... ...torgrufva stock, while to the copper mining was formerly ... ...s stock, and the Drottninge and the deposits are of much ... ...stock and the Kräftklo stock country is that of Falun, w... ...torgrufva stock is the largest oldest stock company in th... ...most completely surrounded by plied the copper for the roug... ...the same as a *ruschel*, that is the royal cipher, and the da... ...ed with material torn from the

Sweden contains several ... ...walls of the fissure and altered Malmohus Län; Nafverb... ...sually the same as the adjoining Örebro; and Atvidaberg, i... ...and amphibole *skölar* are dis-

The Falun mine, the ol... ...ing rocks. The *skölar* are curved situated in southern Dalarn... ...raining. ing to Tornebohm,[2] the ... ...reccia and clays, sometimes also gneiss, poor in mica (a gra... ...ing the highest grade ores of the and granite gneisses, mica ... ...own at Falun was found in the limestone, and bands of sk... ...perfectly pure copper pyrite, with

The Falun mine is 1... ...crystals have only been found in of copper. The present ... ...heir secondary origin. of copper. The deposit ... ...discovered free gold in Falun ore, of cupriferous iron pyrite ... ...slight gold content (2 to 3 gm. per but wedging out in depth ... ...n the ordinary copper ore. The a small amount of gold ... ...strings, which at certain points

The footwall of the ... ...company of a seleniferous galeno- wide band intercalated in... ...s the gold ore without visible biotite, iolite, falunite ... ...gold to the ton. The richer gold phyllite. Certain stock... ...even with the naked eye, may con- defined against the barr... ...gm. per ton. The richest gold ore- ...the Mercka field, where diorites are ...ed by dikes of felsite porphyry, ...shows a band of much altered

[1] R. S. Lorzano, "B... pp. 233 244.

[2] A. E. Törnebohm, ... With 8 plates. *Geol.* ...

...out the more acid main mass. Törnebohm attributes different eruptions, but a simultaneous origin of such ... possible. The "mixed dikes," like the stratified rocks, ...folded, and crushed, as are other narrow, independent ...rite. Sections of such dikes have thus been torn entirely ... their place and left as isolated lumps.

SWITZERLAND

...iss Alps contain copper lodes at Murtschenalp, in the canton ... The ores consist mainly of bornite with pyrite, tetrahedrite, ..., and molybdenite in a finely crystalline matrix of dolomite. ...posits are of probable Permian age and outcrop in the Sernf ...merate.[1]

TURKEY

...r many years the Arghana mines of Asia Minor, between Diabekr ... Kharput, were the chief producers of the empire. In 1899 the high

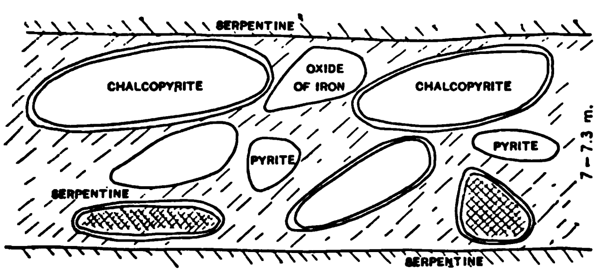


FIG 44.—CROSS-SECTION OF CORITZA OREBODIES, TURKEY

price of firewood caused the furnaces (at Tokat) to close down; but they were reopened in 1902, and produced 5,500,000 lb. in 1904. The ore is high-grade (10 to 12 per cent). There are many other deposits known and formerly worked, but now idle owing to political conditions. The Coritza deposit is similar in nature to that of Monte Catini, as shown by the cross-section (Fig. 44).

[1] G. Tröger, *Berg- und Hüttenmännischen Zeitung*, 1860, p. 305; E. Stöhr, "Die Kupfererz an den Murtschenalp," Zurich, 1865.

IX

COPPER DEPOSITS OF AFRICA

JUST how great a part of the future copper production of the world will be furnished by Africa cannot be foretold from our present knowledge. It is certain that many of the countries of this continent contain copper deposits, many of them worked by the natives for centuries, and some of them of large size, but their reopening must await the building of railways.

At the present time the mines of Namaqualand, in the extreme northwest corner of Cape Colony, are the only important producers. The following notes are taken mainly from the recent work of De Launay.[1]

ALGERIA

A number of small but workable deposits are known to exist in Algeria, and they have been worked in recent years, but the total production for 1906 was only 440 tons.

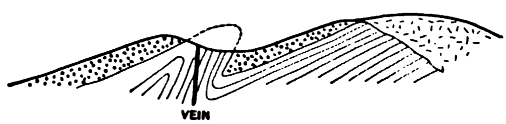


FIG. 45.—CROSS-SECTION OF DEPOSIT AT KEF OUM THEBOUL, ALGERIA. (DE LAUNAY.) VEINS OF MIXED SULPHIDES OF COPPER, LEAD, AND BLENDE, ALL ARGENTIFEROUS, WITH QUARTZ GANGUE

ANGOLA

The Portuguese colony of Angola, West Africa, contains conglomerates holding oxidized copper ores that pass into glance with accessory galena in depth. The conglomerates are part of a series of

[1] "Les Richesses Minérales de L'Afrique," 1904.

Cretaceous limestones and sandstones that dip southwest at an angle of 12 deg. and rest upon the crystalline schists that form the hill country. The deposits are near the railway line and but 12 miles from the Cuanza river, which is navigable.[1]

Portuguese West Africa

The Senze do Itombe deposit is 1½ miles west of the town of that name, and ¾ mile from the railway that runs from the seaport and provincial capital, Loanda, to Ambacca. The Senze area is covered by alluvial drift, underlaid by Cretaceous rocks. The upper beds are white, fine-grained, calcareous sandstones, passing downward into iron-stained conglomerates, with interbedded mica marls resting on fine-grained sandstones, partly calcareous and micaceous. Fossils show the age to be upper Cenomanian.[2]

Cape Colony

Namaqualand, which forms the northwestern portion of Cape Colony, has been one of the notable producers of copper for a half-century. The mines have been successfully and continuously operated since 1852 by two English companies, with an annual production of about 7000 tons. The machinery and equipment of the mines suffered from the Boer raids in 1902, but were restored in 1903, and operations were resumed.

The mines are situated 91½ miles from the coast, and 300 miles north of Cape Town; a railroad connects them with the seaport of Nolloth, a few miles south of the mouth of the Orange river. The district is about 3000 ft. above sea-level, and is mildly rugged and covered by vegetation.

The ore consists mainly of chalcopyrite and bornite, mixed with country rock (diorite). The Ookiep deposit has been remarkably rich, averaging 21 per cent. The ores of the other mines are of much lower grade, that of Nababiep being 6.90 per cent for 1903.

The region is one of old crystalline gneiss and schist, whose bands run east and west, and dip at a low angle northward. The gneiss is traversed by a series of fractures, having a general northeast course, and marked by dikes of diorite. Sometimes these dikes are visible for many miles, the line of dark rock contrasting strongly with the light gray granitic gneiss in which it occurs. Such an exposure is seen run-

[1] F. W. Voit, "The Copper Deposits of Senze do Itombe." *Zeit. für praktische Geologie*, 1899, p. 86.

[2] F. W. Voit, *Zeit. für praktische Geologie*, 1902, vol. x, p. 353.

. . . of the field. Else- . . . the exposures, as at . . . that of the exposed

IX

COPPER DEPOSITS OF

JUST how great a part of the future cop will be furnished by Africa cannot be fore edge. It is certain that many of the cou copper deposits, many of them worked b some of them of large size, but their re of railways.

At the present time the mines of Nam west corner of Cape Colony, are the following notes are taken mainly from

ALGE ... FONTAIN MINE, CAPE COLONY.

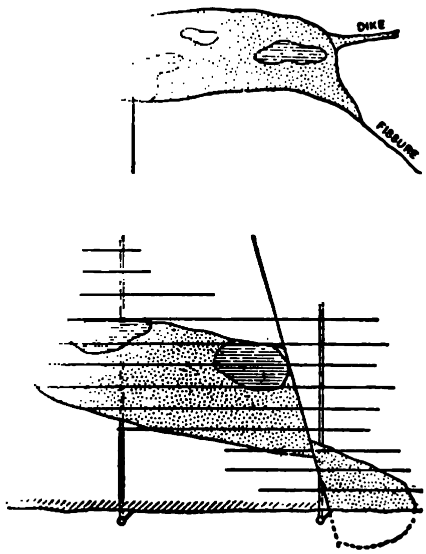
A number of small but workable Algeria, and they have been worked lenticular masses in this diorite duction for 1906 was only 440 to ... of copper, as shown by the ... deposits appear to be formed ... northwest fissures extend-

FIG. ... CROSS SECTION OF DEP... VEINS OF MIXED ... ALL ARGENTIFEROUS, WITH ...

... UPPER OREBODIES, TWEEFON-

The Portuguese colony ... glomerates holding oxidiz ... perceived from the accompany- accessory galena in depth ... orebodies, in the northern part ... 49) across the two upper

ılar mass to have projections
orners, are formed by the con-
wo run out into a barren fissure,
e exposures are good, and the
are is plainly visible.
: richest orebody of the region, there
but the covering of sand and humus
es on the surface. This orebody was
ft. in hight; it is now nearly worked
ornite and chalcopyrite, and is much



VERTICAL AND HORIZONTAL SECTIONS THROUGH OOKIEP MINE. (KUNTZ)

at of the other deposits of the region, averaging 21 per
uspected that the conjunction of the diorite dike, empty
an iron-bearing stratum of the gneiss may be responsible
ter richness of this particular deposit.
h map (Fig. 50) shows fifteen of these deposits, all workable,
t the intersection of the diorite dikes and northwest fissures.
actor may have been the occurrence of bands of iron-bearing

ning from Springbok to Carolus in the … point of intersection. where the diorite is only seen at inte… ore seems to conform Ookiep, all line up, and in a directi… dipping gneisses. The

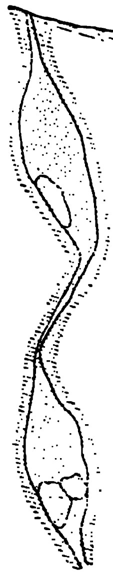
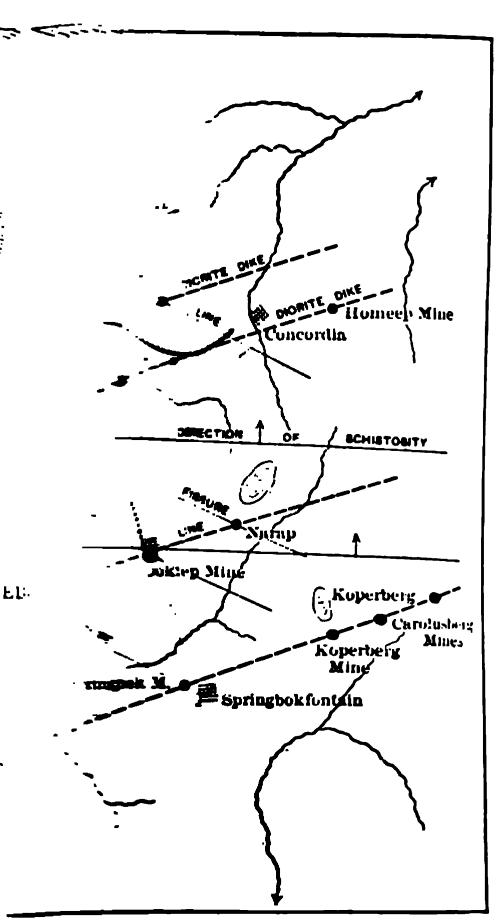


FIG. 46.—SECTION OF OREB…



…MAP OF LITTLE NAMAQUALAND, CAPE COL-

dikes. The orebodies f… dike. This rock ordina… green-stained outcrop, b… at points where the dike i…

FIG. 47.—HORIZONTAL

… an accessory constituent of the diorite, and ing across the gneiss. … hornblende, augite, and mica of the normal ing section (Fig. 46) … apparently the first mineral replaced. Noth- of the district. The … character or extent of replacement. The

posit of Narrap to the eastward, and Naba-
ite being plainly seen to be the ore-carrier at
orp body is a very large one, but the ore occurs
rite. It yielded 6121 tons of 6.90 per cent ore
l by a shaft 600 ft. deep. The Narrap deposit
ntly been reopened, the shaft being now 330 ft.
pper Company operates the three mines last
erberg and Carolus mines on the next dike south.
amaqualand Copper Company, situated on the first
Ookiep, have been abandoned because the ore is
and low in copper.

es at Tweefontain can be followed by the eye far to
t, showing a dark patch on the mountain-sides. To
the Concordia dike line is seen, and the abandoned mines
qualand Copper Company. Still farther south the Naba-
Narrap line is visible, with the mines of the Cape Copper
nd the southern horizon is bounded by a dark line of hills
rolusberg, Koperberg, and Springbok, the so-called Spekta-
e mine of that name lying farther west.

t per unit of copper in the Namaqualand deposits is 7.02d.,
based on 18.5 per cent ores, while the Spektakel mine pro-
per cent ores.

,05 two of the five payable mines of the state were abandoned (the
bok and Spektakel). The Ookiep is nearly exhausted—of the
per cent ores, at any rate. Nababiep, the most actively worked
e, produces 1000 tons a week of 6 to 6½ per cent ore. The Ookiep
t is mined for flux.

Congo Free State

Katanga. — Copper deposits of extraordinary size and richness occur in Central Africa, in Katanga, the southeastern province of the Congo Free State. The region is richly mineralized, and contains workable tin deposits and numerous gold placers, in part due to the disintegration of the copper deposits and in part to the presence of gold quartz veins. The region is drained by several large rivers that form the head waters of the Congo lying to the west of Lake Tanganyika. The entire region is covered by the concessions granted the Tanganyika Concessions, Ltd. It is at present inaccessible, but is not very far west of the line of the

[1] "Les gisementes métallifères du Katanga," 1894, pp. 29–43.

Cape to Cairo Railway, while a railway line is under construction to the region from Loanda on the west coast.

The copper region has been visited by several explorers, and more or less fragmentary accounts of the copper deposits are given in many papers.

According to the descriptions of Cornet,[1] the copper deposits of the region are, for the most part, found in the Moachia system of primary metamorphic rocks, devoid of fossils, over this immense area, but

FIG. 51.—MAP OF KATANGA COPPER REGION, CONGO FREE STATE, AFRICA

supposedly Silurian. The deposits are said to be, like those of Niari probably chalcopyrite ores in quartz, the natives having worked only the oxidized ore of the region. They occur in beds, impregnations stockworks, etc., supposed by De Launay to be probably of the familiar Norwegian type, strings of lenses, of masses, or simple fahlbands.[1] The deposits often have great gossan caps, and all appear to be in metamorphic schists. Being in talcose and silicious schists, the primary ore is less profoundly altered.

[1] *Loc. cit.*, p. 130.

According to Buttengenbach,[1] a rich copper deposit, composed of chalcopyrite, pyrite, and magnetite, occurs at Kambove, in the south of Katanga, and its weathering supplies the placer gold of the streams.

Another deposit occurs in the grit and quartzite hills above the Dipeta River at Fungurume, northwest of, and at Likasye, south-southwest of Kambove. The latter ore carries 22 per cent copper, .000041 silver, and a trace of gold. Both these deposits lie within the limits of the Tanganyika Concessions, Ltd. Extensive exploration and development work was done on the copper deposits of the region in 1904–1905, under the guidance of competent engineers. According to the company's report, from which the following synopsis is prepared, the deposits are not only of extraordinary size, but will average 15 per cent copper.

The Tanganyika Concessions, Ltd., covers a mineral belt in Katanga, Congo Free State. This belt is on the north side of the Congo-Zambesi divide, and is a well-wooded, well-watered, sandstone country.[2] The mining of copper is likely to be the most important industry of Katanga. The native workings are extensive but shallow.

For a belt 175 miles long, running northwest and southeast, there are deposits of high-grade oxidized copper ores of extraordinary size. The ore consists mainly of malachite in a highly silicious gangue (30 to 35 per cent excess SiO_2), but iron and limestone occur in abundance near by. The deposits have been explored for two years and to a depth of 200 ft. They lie convenient for open-cut work. The ore consists of impregnated sandstone, in definite beds. Four important areas have been prospected, viz:

(1) Areas west of Lualaba river.

(2) Areas between Lualaba and Dikurwe rivers.

(3) Areas between Dikurwe and Lufira rivers.

(4) East of Lufira river.

At the first-named (Lualaba) there are three mines. Native workings show an orebody 1500 ft. long by 400 ft. wide of 14 per cent ore. Orebodies of all three mines crop as low hills. At Kolvezi they show quartz between laminated sandstone, with strike northeast 6½ deg. east., dip 65 deg. north., and 4700 ft. above tide.

The Musonoi mine, 1½ miles north of the last, shows two reefs, one 177 ft. wide, with dip 55 deg. north, the other, 116 ft. with 62 deg. south dip. Value 10 per cent.

[1] H. Buttengenbach, "Les dépôts aurifères du Katanga." *Bulletin* of the Société Belge de Géol., Pal. et Hydrol., 1904, vol. xviii, *Memoirs*, pp. 173–186.

[2] Pamphlet issued by the company, 1906, p. 21.

Dikuiwe orebody forms ridges 100 ft. high and a half mile long at an elevation of 4900 ft. on the west side of Ruiwu river. The quartz reef is low-grade, but the sandstone is 28 ft. wide and runs north 21 deg. east to the north-south with dip 54 deg. east.

The deposits of the second area are low-grade, 6 to 9 per cent, and consist of laminated sandstone, the porous reef quartz carrying no copper. The Kakanda vein is 130 to 150 ft. wide. Fungurume mine has 100 to 120 ft. of 6 to 8 per cent sandstone ore, and is 7000 ft. long.

The Kabolela mine shows a 57-ft. seam of ore, with exposures for a mile.

The Kambove is the largest but not a typical deposit, since it forms a hollow and not a hill. The unsorted ore averages 14.28 per cent, occurring on a lens 500 ft. wide in indurated shaly sandstone. According to T. Bayne, it consists of huge lenses of high-grade carbonate ore with layers of poor grade and some of intercalated country rock. The orebody is 3000 ft. long and 500 ft. wide, averaging 16 per cent.[1]

The Likasye mine, shown on one shoot, is said to be 700 to 800 ft. by 300 ft., with a dip of 10 to 26 deg. and carrying 16½ per cent.[1]

Egypt

Egypt has copper deposits, one of which, known as "the mountain of copper," is in the upper Nile region, but they are undeveloped and of unknown value. In the vast interior region it is known there are many undeveloped deposits, but until railroads are built even the best ones are of little value.

French Congo Region (Niari)[2]

The Niari basin, lying along the river of that name, between Loudima and Brazzaville, next the Congo Free State, contains deposits that were worked for centuries by the natives, and supplied a large part of Central Africa with copper. They are now idle, as the Europeans imported copper for the natives, but could not work the mines on account of the prohibitive cost of transportation of machinery and supplies.

The deposits occur in a region of nearly horizontal magnesian (Devonian?) limestones, resting west of Loudima, on crystalline schists, and unconformably overlain in the Haut Niari, between the two principal

[1] Tanganyika Concessions, Ltd., Managers' and Engineers' *Reports* on Gold, Copper, and Tin Discoveries of Katanga, April, 1905.

[2] De Launay, *loc. cit.*, p. 124 (gives bibliography).

copper districts, by the conglomerate of the Karoo formation. The limestones are compact, blue-gray rocks.

The native workings are not over 30 ft. deep, and show glance, tetrahedrite, etc., with the usual carbonates and oxides above. Barrat has described the Mindouli deposit.[1]

Gabon

Deposits of malachite, glance, and gypsum occur in Permo-Triassic sandstones, sedimentary rocks in the region of Monts du Cristal.[2] Their proximity to the coast renders them workable.

German Southwest Africa

Copper exists at the Otavi mines and at Otyizongati. The latter deposit has lately been opened, a trial shipment of 100 tons sent to Germany yielding 18 per cent copper.[3]

Morocco

This contains several copper deposits, the localities known being at Tadlah, near Mekinez, south of Tangier, and Mesfiwa, near the east end of the road from Mogador, on the Atlantic coast.[4]

Natal

Copper lodes occur in the Nondweni district of Zululand, in quartzite, and the veins are traceable for miles.[5]

Rhodesia [6] (Matabeleland)

Rhodesia, Bechuanaland, and Portuguese East Africa contain a number of copper districts in which ancient workings and small mines show the existence of valuable deposits of copper ores. Besides those of the Lomagundi and Victoria districts, there are deposits in the northwestern part of Rhodesia.

Numerous copper discoveries have been made in Rhodesia, but the production for 1906 was but 17 tons. The Northern Copper Com-

[1] M. Barrat, "Géologie du Congo," *Ann. des Mines*, 1900, pp. 460–466, 499, 500.

[2] De Launay, *loc. cit.*, p. 123.

[3] *Mining Journal* (London), vol. lxxviii, p. 706.

[4] De Launay, *loc. cit.*, p. 309.

[5] *Mining Journal* (London), vol. lxviii, 1905, p. 706.

[6] C. Brackenbury, "Some Copper Deposits in Rhodesia." *Transactions* Institution of Mining and Metallurgy, May 17, 1906.

pany exhibited at the St. Louis Exposition fine samples of glance and bornite from the Sable Antelope mine, and the Rhodesia Copper Company showed samples of carbonate ore in schist and dense black gneiss and amygdaloidal trap. An unusual combination of chalcopyrite, calcite, and gypsum, with satiny malachite, came from the Silver King shaft.

Copper occurs at Kameels Port, about 45 miles above and northeast of Pretoria, in the mineral belt extending from Mapocha country across the Oliphant and Moos rivers.

Extensive workings occur in the Murchison range near Palabora, where sulphide and oxidized ores occur with magnetite in marbles and silicious metamorphic rocks.

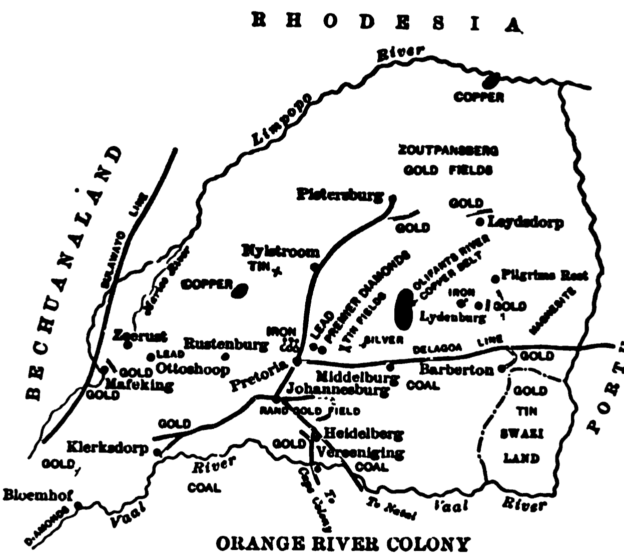


FIG. 52.—INDEX MAP SHOWING LOCATION OF COPPER OF THE TRANSVAAL REGION, SOUTH AFRICA

Lomagundi District. — The Alaska mine is remarkable for the great size of its old workings. It is situated 90 miles northwest of Salisbury, and 13 miles from the Rhodesia banket. The deposit consists of copper impregnated silicious and calcareous schists grading into quartz and limestone, and forming part of the Archean schist area which covers a large part of Rhodesia. The copper occurs as malachite, richest in the calcareous schists as incrustations and thin seams, and as chrysocolla and scanty oxides. Though low-grade, the orebody is large; the ancient workings, which are traceable for 1700 ft., being 600 ft. wide in places and 70 ft. deep, with 50 to 70 ft. of pay streak worked. The property is accessible from the Ayrshire mine, 30 miles east, the terminus of a projected railway line.

The Silver Reef group is 40 miles northeast of the Alaska by wagon road, and 20 miles northwest of the Ayrshire gold mine. The deposit consists of copper glance and carbonate in pockets and stringers in the schists. Regular veins are lacking, but the rocks are contorted, and quartz outcrops occur along lines of disturbance and fracture.

The old workings show widths of 60 ft. and 100 ft., and in one trench a length of 1200 ft. and a depth of 60 ft. In places schists contain iron pyrite, and a seam of impure graphite was noted.

Victoria District. — The Umkondo mine has old workings 1500 ft. long and in places 300 ft. wide. The deposit lies 115 miles by wagon road east of Victoria, 130 miles south and west of Umtali, on the Beira-Mashonaland Railway. The ores consist of carbonates impregnating beds of shale and of quartzite. These rocks strike northwest and southeast, and have an average dip of 16 deg. to the northeast at the mine.

The rocks are part of a series of sandstones and shales lying beneath the coal measures, and are probably middle Paleozoic in age. The beds are cut and faulted by dolerite and other igneous rocks, and the sandstone altered to quartzite. The copper ore occurs in two beds of light-colored shales, the first, 5 ft. thick, being at the base of a series of shale beds and lying just above a well-marked and persistent bed of quartzite 40 to 85 ft. thick. The bed averages 5 per cent copper. The second bed is about 3 ft. thick, is said to carry 10 per cent copper, and lies in the quartzite 20 ft. below the first, consisting of two or three clayey seams.

The ores occur only where the rocks are fractured by a northwest and southeast zone of fracturing and a second plane at right angles to it. The ores are found in patches or shoots, and only in a synclinal fold between the main strike fault. The ore is mainly malachite and azurite for a seam nodule and incrustation, along bedding planes of shales and fracture lines, in the quartzite and as nodules scattered through the rock. Diamond drill holes show specks of chalcopyrite in dolerite 600 ft. down, and the amygdaloidal basalts near by hold a little glance and native copper. The water level is 100 ft. below the surface, but sulphides occur only at greater depths. The coal measure series is 20 miles distant.

Similar deposits occur elsewhere in the Victoria district, 18 miles east of Umkondo and across the Sabi river, and in the Melsetta mountains a few miles farther east. At the latter place stringers of sulphide ore occur in veins inclosed in quartzite and diorite.

North of Umkondo copper ores and tungsten occur in amygdaloid basalt bordering a pink granite. The Malilanga property, 120 miles southeast of Victoria, shows copper workings in hornblende gneiss.

TUNIS

Copper mines exist at Chouichia [1] which have been worked on a small scale for some years. The ore is smelted at the mines to a high-grade matte.

Copper exists also on the island of Bizerta, in a vein in diorite. The vein averages 3 ft. thick, and carries chalcopyrite in a soft argillaceous gangue, the ore averaging 5 per cent copper. A depth of 300 ft. has been reached. Other parallel veins outcrop on the mountain-side, one of which carries rich carbonate ore.

[1] *The Mining Journal* (London), Jan. 12, 1907, p. 46.

X

THE COPPER DEPOSITS OF ASIA AND OCEANICA

THE copper resources of Asia are undoubtedly great, though largely undeveloped, the mines of Japan being the most important. In northern Asia copper deposits are known at many localities. The great Chinese empire has produced copper from shallow pits for a thousand years past, and its mines, like those of Japan, will some day be important producers. The copper deposits of India are many, but recent investigation has shown that if reopened they will not materially add to the world's production.

The copper deposits of the East Indian region proper — Siam, the Malay Peninsula, Borneo, etc. — are as yet undeveloped, though the metal is said to occur at many localities. The copper-bearing stream gravels of the Philippines and the known extent of the deposits on Luzon indicate that they may soon be the basis of an important industry. The deposits of Siberia are practically undeveloped. They are treated under Russia.

Korea has some copper mines at Kosan, Hamgyonado, under concession to the Japanese copper firm Mitsui.[1]

CHINA

Copper is found in several provinces, the best-known deposits being probably those of Yunnan, which have furnished the copper for the "cash" of the empire since time immemorial. The metal is also found in Tien-Tchang and Koui-Tcheou. At the last-named locality, as in Yunnan, the metal occurs in two kinds of deposits: (1) in limestone; (2) in red sandstones near green porphyrite or melaphyre intrusions. The metal occurs sometimes native but mostly as a sulphide, the metal containing gold and silver and sometimes nickel forming the "white copper" of Kien-Tchang.

[1] *Engineering and Mining Journal*, March 3, 1906, p. 447.

Yunnan, Kwangtung, and Kwangsi. — Southwestern China, a region opened up by an extension of the Indo-China (French) Railway, contains numerous small copper mines. One at Veitaachan, 7½ miles south of Mientien, works a copper-bearing bed of the Permo-Triassic grits, yielding 30 to 40 per cent highly silicious ore, that is packed to Yunnan. A score of people are employed. The tin seams in the red clays of Malaken pass downward into copper ores.

Tung-chuan and Wisi are the principal centers of copper mining in Yunnan. At the Lupu mine the copper ores occur in a bedded horizontal vein in porphyrite. The ore contains native and red oxide in a barite gangue.

The more important Tangstan deposits occur (at Laochang openings) as a stockwork, and yield about 500 tons of copper annually. The ore is carbonate, with some copper pyrite, and is mixed with chalcopyrite from Laosinchang before smelting with wood.[1]

Low-grade copper ores occur at a number of places in the Yangtse valley, mainly as copper pyrite with associated bornite.

In the province of Hupeh, not far from Ichang, there are large beds of low-grade cupriferous shale.[2]

Red sandstones impregnated with copper occur in the middle of Sze Tschouai and in Koui Tscheou and Yunnan,[3] being associated with green porphyrite or melaphyre in Yunnan. Copper ores in limestone also occur in the provinces just named, the ores being sulphides carrying gold, silver, and rarely nickel. The production is about 1100 tons a year.

India

India contains many ancient copper mines, worked before British domination, but now idle, though several attempts have been made by European companies to reopen them. The deposits are mainly found in the Himalayan region, in the northern part of the northwest provinces, from Darjiling to Punjab. According to Stephens,[4] who spent two years exploring and testing the old properties (Rai mine), there are two types of deposits, viz. regular and irregular. The latter occur mostly at Garhwal, and have been extensively mined at Dhanpur,

[1] A. Leclère, *Ann. des Mines*, 1901, ser. 9, vol. xx, pp. 287, 402, 405–492, 12 pl.

[2] F. Lynwood Garrison, "Mining and Industrial Development of China." *Mining and Metallurgy*, February 15, 1901, p. 106.

[3] *Zeit. für praktische Geologie*, 1898, pp. 83, 167.

[4] "Geology and Mineral Resources of Northwest India." *Transactions* Institution of Mining and Metallurgy, London, vol. x, 1901–1902, p. 393.

Dabri, and Al Agur. The Dhanpur (Dhunpoore) deposits, described by Henwood,[1] occur as bunches of chalcopyrite and bornite, at joint intersections in limy clay slates. According to Stephens, the deposits at Dabri and Dhanpur are in silicious limestones, overlaid to the northeast by rhyolite and garnetiferous schists; to the southeast black Cambrian shales, quartzites, and red and green flagstones appear. The orebodies occur in limestone and other rocks, are 15 to 30 ft. wide, and consist of a mass of brecciated limestone and quartz. These workable orebodies occur where vertical and horizontal veins intersect. These quartz veins are narrow, closely spaced, often but a foot apart, and contain chalcopyrite, glance, etc., in the quartz. They cross a series of horizontal veins 2 to 8 in. thick. The Dabri deposit is similar. The Al Agur deposit is a stockwork in which thin veins of quartz, about a foot apart and never over 4 in. wide, traverse quartzite and ancient volcanic rock. The ore carries about 5 per cent copper, and consists of carbonate, tetrahedrite, and chalcopyrite. The deposit has a 40 deg. dip and is 20 to 30 ft. thick.

The deposits occur in a copper zone traceable for nearly 50 miles. The rocks of the zone are talcose slates and schists, which adjoin and are generally considered a part of the great limestone series of the region. In this zone the copper veins occur sometimes at the contact between limestone and talcose slates, but mostly in slates. The veins are from 2 to 6 ft. wide, and usually have well-defined walls. The ore occurs in shoots, seldom over 6 ft. in length, separated by barren "courses." The Rai mine, recently opened, cuts four veins in a shaft 80 ft. deep. The ore consists of copper pyrite and bornite, disseminated through the country rock, and even in the ore shoots it is not rich enough to stand transportation.

Another copper range occurs 180 miles from Calcutta, and is traceable for 80 miles in length. The primary ore is low-grade, but the richer surface ores were worked for centuries by the natives. The deposits are about 2 to 3 miles distant from the railway line, and a company has been organized to develop the more promising properties.

Deposits of low-grade copper ore occur in the provinces of Garhwal and Kumaon in the Mid-Himalayas, in the Deoangur spur, which stretches as a long ridge for some miles from near the Niti Pass into Tibet. The geological features of the locality consist of a series of schists, some chlorite- mica- and hornblende-, but with quartz-schist very largely predominating. In places huge lenticular masses of quartz and

[1] Phillips-Lewis, *op. cit.*, p. 154, fig. 51.

decomposed felsitic quartzites occur imbedded in the schists. These successive bands of schists all partake of the general lenticular structure, widening from mere streaks into great thicknesses and then dying away, the next layer gaining in thickness as the first dwindles. The copper ore occurs in one of these lenticular masses of foliated mica-schist, or, rather, in a band which contains more mica than most of the others. This band is also of more or less lenticular shape, and varies in thickness from a few inches to nearly 40 ft., the whole of it being by no means uniformly mineralized. The mineralized portion may be said to be nearly 700 ft. in length.

The cupriferous schist consists principally of very thin lenticules and minute bands of quartz, much broken up, and separated by thin foliations of mica. Some of these quartz bands are much wider, more like nodules, and are completely surrounded by a thin film of mica impregnated with copper pyrites. The whole mass has evidently been subjected to great pressure and at the same time to lateral movement. The copper is carried in the form of copper and iron pyrites, which have been distributed as an impregnation of the schist; as irregular masses and bands of pyrites, some a few inches wide; and as strings, nodules, and even little veins in cracks in the lower nodules or lenticules of quartz. Assays of the material broken from various drifts across the schist give an average of nearly 2 per cent of metallic copper.

There are numerous old workings, many down to water level, in Bengal, in the Singhbhoom district. The Radjahi Copper Company unwatered and prospected ten shafts in 1892, and made small shipments of hand-picked 13.5 per cent ore. The crude ore, varying from 4 to 7 per cent, formerly unworkable, is now close to the railroad.

New Caledonia

Numerous copper deposits are known in the Indian archipelago, but there are no successful mines in operation. The largest deposits are in New Caledonia.

New Caledonia, midway between Samoa and Australia, is best known for its wonderful mines of nickel ore. It contains copper deposits on both the east and west coasts and in the interior. The largest are at the northeast end of the island in the Diahot district, in sight of the town of Pam, a short way up the Diahot river.

The Pilon and Ao mines, owned by the Caledonia Copper Company, are the largest. The ores occur in vertical northeast and southwest quartz reefs, cutting black slates, mica schists, and chloritic, talcose, and amphibole schists, and gneissoid diabase. The deposit dips at 30 deg. to the west. The ore occurs in lenticular shoots 50 to 100 ft. long and 4 ft. wide, in a black slate filling. There are five zones cut on strike. The larger shoots are shattered and carry more pyrite and less copper than the small lenses. The ore consists of chalcopyrite and bornite, with accessory galena and blende. Two thousand tons hand-picked ore averaged 10.1 copper, 40.9 silica, 13.9 sulphur, 11.4 iron, 7.4 alumina. The mine shaft is 380 ft. deep.[1]

The Balade group of deposits are mainly copper pyrite interbedded with and impregnating hornblende and glaucophane schists. The mines were abandoned in 1884.

Persia

Copper is very plentifully distributed throughout Persia, but the workings are few and primitive and the output insignificant. The Semnan deposit consists of disseminations and veinlets of oxidized ore in flat layers in claystone, in part silicified. The ores average 3 per cent.[2]

The Philippines

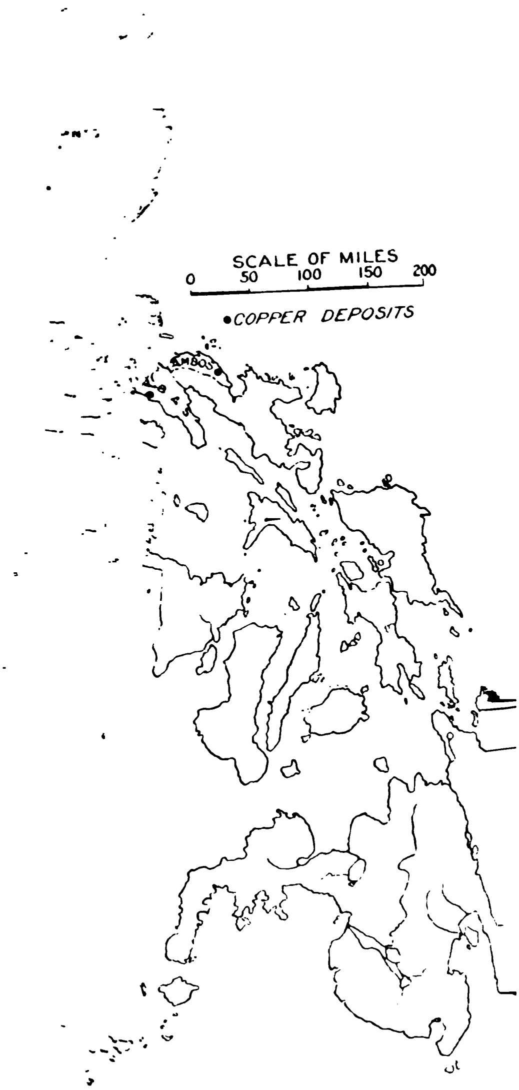
Copper has not yet attracted the attention which has hitherto been given to coal and gold. The best-known occurrence of copper in the Philippines is in the province of Lepanto, which adjoins Benguet on the north. Sulphide ores predominate here in the Mancayan-Suyoc mineral region, whose copper deposits were extensively worked in 1850 and later. Their yield was materially increased during the period 1864–1874, when a Spanish-Filipino company produced 1100 metric tons of metallic copper in the vicinity of Mancayan. A number of new claims are now being developed by an American syndicate.[3]

In Suyoc, just south of the last-named district, several copper deposits

[1] References: E. A. Weinberg, "Copper Lodes of New Caledonia," *Transactions* Australasian Institute of Mining Engineers, vol. vii, 1901, p. 138; F. Danvers Power, "Mineral Resources of New Caledonia," *Transactions* Institution of Mining and Metallurgy; Louis Pelatin, "Les Mines de la Nouvelle Calédonia," *Le Génie Civil*, Paris, 1892, and Government book on same, 1904; E. Glasser, "Rapport à M. le Ministre des Colonies sur les Richesses Minérales de la Nouvelle Calédonia." *Ann. des Mines*, 1903, ser. 10, vol. iv, pp. 299–392, 397–536; 1904, vol. v, pp. 29–154, 503–620, 623–701.

[2] J. Maclear, "Notes on Persian Mines," *Transactions* Institution of Mining and Metallurgy, Vol. III.

[3] A. J. Eveland, *Bulletin* No. 4, the Mining Bureau, Manila, P.I., 1905.



KNOWN COPPER DEPOSITS OF THE PHILIPPINE ISLANDS. (McCaskey) are now being developed. The ores consist of auriferous tetrahedrite, tennanite, enargite, and luzonite, the Government samples showing 9.7 to 32.9 per cent copper and 85c. to $4.75 per ton in gold.[1]

In the Buld river district, veins of refractory gold-copper ore — the Copper King claim and the Gray Horse — show smelting ores.

In Pangasinan, in the foothills of the northern Zambales range, near Salasa, 10 miles west of Dagupan, copper veins rich in gold are being developed.

Batangas province contains copper in the Loboo Mountains, 600 ft. above sea-level and 5 miles from a good harbor. The veins are of two systems and of the fissure type, in dioritic rock. These are ½ to 2 ft. wide, and run east and west or north 45 to 57 deg. west, running with the range. The ore carries bornite, chalcopyrite, tenorite, cuprite, chalcocite, malachite, and azurite, with gold and silver values. The gangue is quartz.[2]

[1] *Sixth Annual Report*, Chief of Mining Bureau, Philippine Islands, Manila, 1905, pp. 16, 17.

[2] W. D. Smith, *Phil. Journal of Science*, vol. i, pp. 617 *et seq.*

[illegible] OF JAPAN

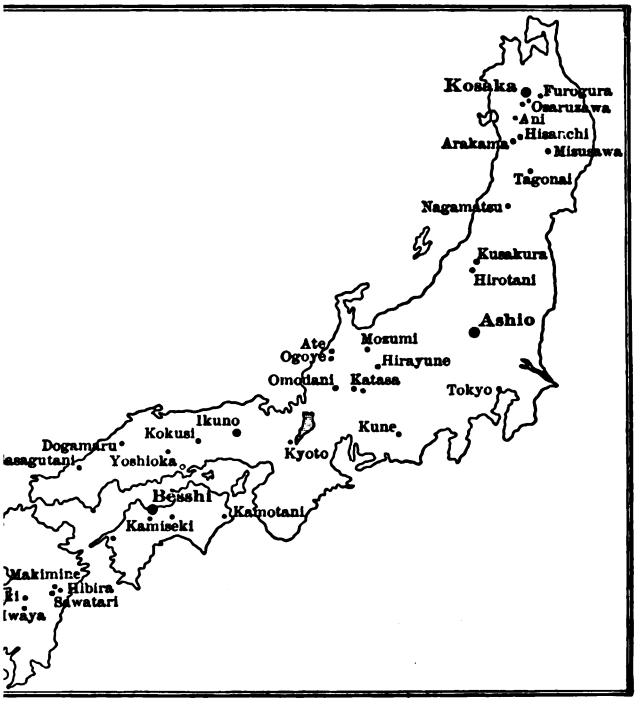
[illegible] f Japanese mining. It occurs [illegible] and, and has been mined from [illegible] adaptation of modern industrial [illegible] and smelting have been revolu- [illegible] up to date in its equipment and

[illegible] greatest copper mines of the [illegible] mines of small production but [illegible] Three great mines furnish one-half of [illegible] tons, and there are 14 mines, [illegible] yearly. As the production of the [illegible] two-thirds of the output is exported [illegible] world's copper market.[1] The pro- [illegible] of which the copper is an importan[t] [illegible] which contain gold and silver values [illegible] three main types: (1) veins; (2) im- [illegible] volcanic rocks; (3) lenses of cuprif- [illegible]. The three greatest mines of the [illegible] to which most, if not all, the lesse[r] [illegible]. These three, Ashio, Kosaka, and Besshi [illegible].

[illegible] are the largest in Japan. They are [illegible] of Tokio and 18 miles from Nikko, in middle [illegible] of Palaeozoic clay slates and hornstones cut [illegible] and rhyolite in which the veins occur [illegible] of veins, some thirty of them being worked [illegible]

[1] [illegible] study of the remarkably complete mining exhibit of [illegible] upon Japanese Geological Survey reports, and upon [illegible] Dr. [illegible], of the Imperial University, who is a specialist

; form a coördinated system of conjugate fractures, with two .ions, viz. northeast to southwest and northwest to southeast. n consists of veins in pairs with opposed dips of 60 to 70 deg. .re not wide, averaging 5 to 6 ft. thick, and so far have been : 400 ft. below the lowest adit. The ore consists of pyrite, e, and quartz, and is relatively high-grade, the smelting ore 5 per cent, though lower-grade ore is also mined and milled. oots are long, averaging 1000 ft., and are 6 ft. thick. The was 14,622,500 lb. in 1904.



INDEX MAP OF JAPAN, DOTS SHOWING LOCATION OF COPPER DEPOSITS

is of other localities, as, for example, those of Ani, belong to f quartz veins with predominant carbonates, together with fluorite. The Ozarugawa, Kusakura, and Arakawa deposits ; class, the veins occurring in tuffs and intrusive bodies of ıd propylitic augite andesites that cut Tertiary beds. The

ores consist of pyrite and chalcopyrite with hematite, and lead, zinc, and silver sulphides, besides quartz, calcite, rhodochrosite, and barite. In the Kusakura mine the proportion of specular hematite increases downward. Similar lodes in Paleozoic strata occur at Yoshioka, Sassagatani, and Dogamaru, being dependent on granite and diorite intrusions near by.

Kosaka. — The Kosaka mine, representing the second type, is situated in a hilly region in the extreme northern end of Japan. It is an old silver mine, formerly supposed to be worked out, but now likely to prove the largest copper deposit in all Japan. The region consists of andesitic rocks, mostly tuffs, cut by intrusive masses of rhyolite. The ore deposit is an impregnation of porous volcanic tuff beds alongside of a rhyolite (or dacite) contact. There is a sharply defined hanging wall, but the ore fades gradually into the footwall country. The deposit is of enormous size, being from 100 to 600 ft. thick, known for 2500 ft. in extent, and proved by drill holes to 1700 ft. in depth. In the open cuts the deposit varies from 20 to 140 ft. across, the deposit extending with the bedding of the tuffs. The ore consists of chalcopyrite and pyrite, with more or less associated sphalerite, cementing and impregnating a volcanic tuff of varying character, being partly a conglomerate and partly a fine grit or arkose. Three grades are mined: (*a*) "black ore," a zinkiferous sulphide ore with 2.2 per cent Cu, 2 oz. per ton of silver, and 65c. gold per ton. This ore carries 12 to 18 per cent zinc, and from 20 per cent up to 35 per cent of barite. (*b*) The pyritic ore proper; carries but 1.8 per cent copper, and rarely holds tetrahedrite and galena. (*c*) Silicious ore, low-grade, but necessary in smelting. The production was 9,500,000 lb. in 1905.

Besshi. — The Besshi mine is located in the great island of Shikoku near Kyoto, in southern Japan. The deposit is 3600 ft. above tide, in a mountainous region. The district is one of chloritic and graphitic schists, which near the mines contain bands of piedmontite schist, the whole generally enveloped in quartz-schist.

The deposit, an immense mass 6000 ft. long, 4 to 30 ft. thick, and over 1750 ft. deep, is intercalated in crystalline schist, and is often called a bedded deposit. The course of the orebody is north 30 deg. east, and it has been worked for 6000 ft. in length. It is usually 10 to 20 ft. thick, and not over 60 ft. The bed dips 45 deg. northeast, and is worked by an inclined shaft.

The ore consists of chalcopyrite streaks in crystalline pyrite with bands and curved and broken slivers of blackish schist. The ore averages between 3 and 4 per cent copper. The vein is faulted by east to west step-faults at 45 deg. to the strike, that dislocate the orebody 10 to 20 ft., and never over 60 ft. The production was 10,425,800 lb. in 1902.

The Kune mine is of the same type, there being three lens-shaped orebodies in Paleozoic schists resembling those of Besshi. The upper bed is 6 ft. thick, and the middle one 12 ft. thick. The largest orebody is the lowest, and is 80 ft. thick, 1000 ft. long, and opened to a depth of 400 ft. The production in 1904 was 30,000 tons of 6 per cent ore. The orebodies are 60 ft. apart, lying one over the other. The dip is 50 deg. north-northwest. The Hibira, Hyuga, and Itsuki pyrite orebodies are of similar type, but occur in Carboniferous slates near intrusive bodies of quartz porphyry.[1]

Among the lesser but important copper mines of the country those of Ani, Ozarugawa, Kusakura, and Ogoya are of interest as being of the spathic copper type. In the Kusakura mine, the largest of those named, the specular iron increases with depth.

Similar veins, cutting the Paleozoic rocks near Plutonic intrusives (granites and diorite), occur at Yoshioka, Sassagatani, and Dogamaru.

The Ozarugawa deposit consists of a breccia of propylitic andesite, a greenstone probably in part, at least, an andesite tuff, with a cement of pyrite, bornite, chalcopyrite, and green quartz. The ore is vuggy, and the quartz in place shows curly structure. In part the ore consists of coarsely massive chalcopyrite, showing cavities left by removal of pyrite, or of finely granular pyrite with quartz vugs and secondary veinlets. It suggests the Kosaka and Boundary creek type. The mine belongs to the Mitsu Bishi Company.

The Arakawa ore varies from a mixture of chalcopyrite and bornite, showing post-mineral fractures filled by white quartz veinlets and vugs, to a compact mixture of chalcopyrite and quartz. The country rock is a mottled green brecciated rhyolite and a dense propylitic andesite.

The Makimini deposit consists of finely granular chalcopyrite in lenses in a slaty greenstone and lustrous clay slate, the latter showing interbanded chalcopyrite.

[1] Literature: "Mining Industry of Japan," Wada Tsunashiro, Department of Agriculture and Commerce of Japan, 1893. This gives a full account of each mine and is published in English. "Outlines of the Geology of Japan," published in English by the Japanese Government. Pamphlets issued by the Imperial Commissioner, at St. Louis, Mo., 1904.

XII

THE COPPER DEPOSITS OF AUSTRALASIA

THE Australasian commonwealth ranks sixth in the list of copper-producing countries of the world, the yearly output being about the same as that of Chile and Canada. The unusually high-grade ores for which the colonies were famous for so many years are now, however, produced in but small quantity, the main production coming from half a dozen large deposits of relatively low-grade ore, and from about fifteen lesser producers. In Australia itself, however, there are many deposits in the desert areas of the interior, where lack of water and of railroad transportation prevents the development of any save the richest orebodies.

The larger deposits have proved persistent in length and in depth, being worked to considerable depths; the Lloyd mine at Burraga is 1750 ft. deep, the Wallaroo 2000 ft. deep, and the Moonta 1720 ft. The fact that very low-grade cupriferous pyrite, carrying small gold and silver values, is worked in Tasmania, and that at the Lake George mine, New South Wales, a low-grade, complex, refractory, zinkiferous ore, carrying but 1.1 per cent copper, has been profitably smelted, indicates ability to handle fully as low-grade ores as those found anywhere else in the world. The success of these deposits has led to the reopening of several of the older mines, like that of the Burra Burra, a mine whose early history is almost unique, as it yielded $4,000,000 dividends on a paid-in capitalization of $61,000.

The copper deposits of Australia present considerable variety in character, including bedded lodes in schists, quartz veins cutting across the country rock, and quartz pyrite veins in igneous rocks. The salient facts concerning the most important mines will be given in geographical order.

SOUTH AUSTRALIA

According to the governmental report[1] upon the copper mines of this state, there are 430 copper properties which have been more or less

[1] E. H. Derrington, "A Record of Mines of South Australia," third edition. H. Y. L. Brown, *Government Geologist*, 1899.

extensively developed. Only seven of these are now producing. The best-known properties are the Wallaroo and Moonta mines, situated in the York Peninsula, in the extreme southern part of the state. These

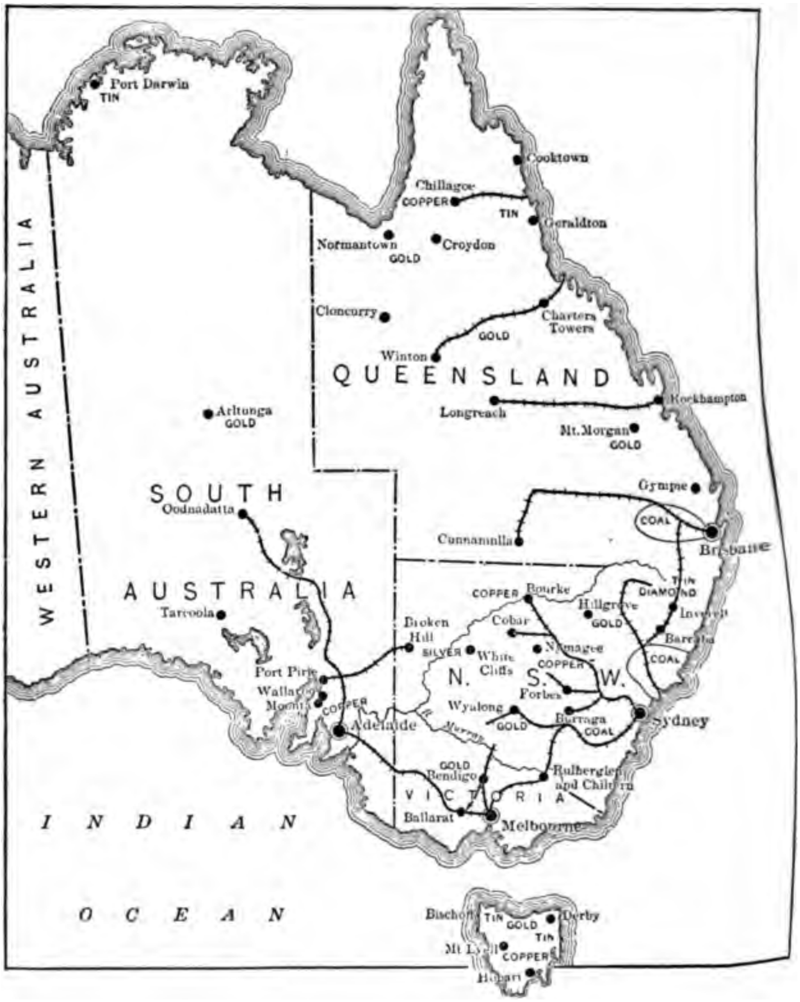


FIG. 56.—INDEX MAP OF COPPER DEPOSITS OF AUSTRALIA

mines yielded 5027 tons out of a total of 7000 tons produced by the colony in 1903. Both mines belong to the same company, but are some 9 miles apart.

Mine.— This is one of the deepest and most produc-
of Australia, being 2000 ft. deep, and having over 20 miles
;. There are three vertical west-northwest and east-south-

ıtry rock[2] is a gray orthoclase porphyry, that is closely jointed,
to small blocks. The joint planes usually show a green coat-
ıibolic minerals, giving the rock a basic look.

›hyry does not outcrop, but is covered by a mantle of calcare-
a recently deposited silicious yellow limestone containing 15
.ica, forming beds of loose or slightly compacted material
:rs into spherical masses. The veins consist of quartz carry-
yrite, some pyrite, and red hematite, with accessory molyb-
ndistinct isolated crystals in the ore. They do not outcrop,
aled by the recent limestone. The veins vary in thickness.
.re 6 ft. thick, and they vary up to 25 or even 33 ft. They
r less parallel, run southwest and northeast, and dip very
ıd 60 deg. to the northwest.

; show rich oxides in the red decomposition clays beneath the
›; beneath this the leached and barren zone is 35 to 40 ft.
oxides, native copper, and black sulphide occur and extend
primary sulphides encountered at about 100 ft. The five or
importance occur in a small area about 1500 meters square.
: characteristic feature of the orebodies is the slight length.
say that each of them consists of a single mineralized
erally of a wide V-shape, the downward point and the axis co-
.h the dip. The amount of ore diminishes with depth, and
ization stops at a depth about the same as that of the hori-
t.h. Each of the ore columns consists of large isolated
.r together. The ore fades rapidly, but with transitions to
rtz; at 7 to 8 meters in depth a fine ore shoot has sud-
ed to a mere film. Elsewhere the vein is choked off and
; a simple film.

ıd of a column the ore disappears without trace of accident;
continues, though slim. A greenstone dike cuts off the min-
e vein becomes barren beyond. The ore pipe consists of an
pockets.

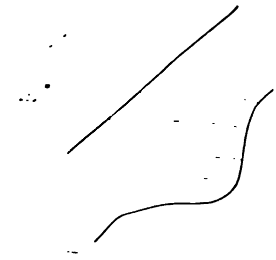
:k, general manager, in *Engineering and Mining Journal*, February 10,

scull, "Note sur le dist. cuprifère de Wallaroo," pp. 544–563; *Ann. des*
., no. 5, 1905.

...al quartz vein is being
... with cross joints and true
... and have a very silicious
... per cent for many years.
... 2.205 per cent ore. This
... to a stoppage of produc-

... diminution in the value of

... exist on the Moonta property,



...ALIA, SHOWING ENLARGEMENT...

...ey are quartz veins in porphyrite
... rock. They carry chalcopyrite and
... They vary from ½ ft. to 20 ft. in
...th of 1720 ft. The veins form two
... deg. east, the other north 40 deg.
... cent copper, which is concentrated
... The mine yielded 61,000 tons of
... It has produced $26,980,730 and
... The maximum production of both

... the sorted and concentrated ore re-
... belonging to the company is approxi-

... *Mining Journal* (London), vol. lxxviii, 1905,

... Works." *Bulletin 26*, Institution of Mining

	Wallaroo Mine Per cent	Moonta Mine Per cent
Copper	13.00	19.00
Iron	26.10	25.26
Sulphur	22.15	17.82
Silver	0.0023 = 15 dwt. per ton	0.0020 = 13 dwts. per ton
Gold	0.0002 = 1 dwt. 7 gr. p. t.	0.0002 = 1 dwt. 7 gr. per ton
Lead	0.25	0.05
Nickel	0.169	0.08
Zinc	0.73	0.041
Arsenic	0.011	0.004
Bismuth	0.0012	0.001
Tellurium	0.001	0.001
Silica	25.19	27.03
Alumina	2.77	2.66
Lime	3.34	0.78
Magnesia	3.17	1.04
Undetermined — Alkalies, Manganese Oxide, Phosphoric Acid, Fluorine	3.1153	6.2308
	100.0000	100.0000

Comparing the Moonta and Wallaroo mines, they are seen to be very different. At the Moonta there are five distinct lodes in hard felsite porphyry, and there is no enrichment at vein intersections, but a "softening" of the lode matter; or, if the inclosing country indicates the proximity of orebodies, there are no bunches of any size unaccompanied by a change from hard feldspathic to soft and altered rock.

At Wallaroo, on the other hand, the country rock consists of various kinds of schist and slates, and the junctions of lodes, or rather of branches, with the main lode are frequently marked by richer ore.[1]

The Parametta mine, in the same district, shows very hard low-grade pyritic ore for 200 ft. down, when soft rock indicates a large mass of 18 per cent ore.

The Burra Burra mine has two veins with a northwest and southeast course, and 70 deg. northeast dip. The inclosing rocks are serpentinized limestones, cherty limestones, blue slates, and argillaceous sandstones. The hanging wall is a thinly bedded limestone; the

[1] Leigh G. Hancock, *Transactions* Australasian Institute of Mining Engineers, vol. x, 1905, p. 348.

footwall is a serpentine regarded as an altered limestone. The veins are developed to some 600 ft. in depth, and in the period from 1849 to 1877 yielded 234,648 tons of 22 per cent ore. The mine was reopened in 1900, and produced 235,000 tons of copper in 1903.

The Hambly vein is a quartz-pyrite vein, with copper present as chalcopyrite. The product was 1060 tons of 17 per cent concentrate in 1903. Smaller mines of future promise include the Lynda, Yetta, Mount Rose, and the Parametta, an old mine reopened in 1903.

New South Wales

This state contains a large number of important copper deposits, producing about 8000 tons of copper annually. The total value of the state's copper production to the end of 1904 was $35,850,000. Copper deposits occur in three districts; viz. (1) Cobar, (2) Central, (3) Coast. Those of the first two districts present certain family resemblances. Those of the third are different entirely. The most important one is the Cobar district, 110 miles south of Bourke, 459 miles west by rail from Sydney.[1]

The Cobar district embraces the subdistricts of Cobar, Mount Hope, Nymagee, Overflow, Girilambone, Gilgunni, Yellow Mountain, and Melrose. The Cobar region is an interior desert area, where water is extremely scanty, and the nearest stream course is 80 miles distant. The district consists of a monotonous, uniform series of slightly undulating plains, with a succession of ridges and occasionally a hill, locally called a mountain. The veins occur near these short "mountain" ridges; and oftentimes the elevation is due to the resistance of the veins (Janin). The Great Cobar, Lloyd, Burraga, Queen Bess, and Cobar-Chesny are the most important mines of this district. The prevailing rocks are of Silurian age, consisting of slates, often silicified, and sandstones with intercalated quartz seams. No eruptives are recognizable unless certain schistose rocks are disguised eruptives. The deposits are all regarded as bedded veins in Silurian schists.

The Cobar property includes three parallel veins. The main vein varies from a few inches to 100 ft. in thickness. The west wall of the orebody is of sandstone devoid of ore. The orebodies are extremely irregular. The ore is essentially a cupriferous pyrrhotite, with 2¼ to 4 per cent copper, and 2½ to 3 dwt. per ton gold, carrying about 16 per

[1] J. E. Carne, "Copper Mining Industry of New South Wales." Geological Survey of New South Wales, 1899.

cent silica. The vein forms a low, inconspicuous ridge in a flat, desert region of Silurian sandstones and schists, the outcrop showing quite small amounts of limonite in isolated patches. Oxidation extends downward for 250 ft. At a depth of 540 ft. the orebody is 450 ft. long, with 150 ft. of solid ore that is up to 70 ft. wide, and consists of nearly solid pyrrhotite, carrying a little chalcopyrite. Copper glance, chalcopyrite, and magnetite occur in the primary ore, while the oxidized ore contains the usual variety of minerals. The ore is notable for the amount of bismuth it carries, which caused considerable trouble in the earlier history of the mine, before electrolytic refining was practiced.

The Nymagee, owned by the Cobar company, shows lenses of cupriferous pyrite in slate, the deposit resembling Great Cobar.

The Lloyd vein is 5 ft. wide, has an ore shoot 700 ft. long, and has been worked to a depth of 1750 ft. It is about a mile distant from the Burraga.

The Girilambone, Mount Hope, and Burraga veins are silicious veins, unlike the pyritic deposits already mentioned.

The Mount Hope mine is 100 miles south of Cobar. The ores are always associated with eruptives, usually andesite and diorite. Like the Cobar mine, there are three parallel outcrops of ferruginous slate and quartz seams, but, unlike the Cobar deposits, there is no well-defined boundary to the orebody.[1]

The Burraga mine is one of the oldest mines of the state, having been discovered in 1877, and yielding large quantities of high-grade ore in its upper levels. The vein, unlike those just noted, is quartzose, and occurs in a belt of highly altered rocks varying from porphyry into schist and slate, much of the gneissoid rock being an acidic rock altered by pressure. The schists have a strike of north 20 deg. east and dip southeast at 36 deg. The vein has a course of north 70 deg. east and a southeast dip of about 20 deg. The orebody has varied considerably in thickness, the usual width being about 6 or 7 ft. The length of the shoot is about 100 ft. The mine is dry, and timbering is dispensed with. The gangue is silicious, and the copper occurs as chalcopyrite. The ore carries about 2¾ oz. of silver per ton, with no gold. The mine contains a large amount of low-grade ore, and has recently been reopened.

The Lake George is a vertical replacement vein on a fault in Silurian slates. It varies from 22 to 30 ft. in width, and consists of a compact fine-grained mixture of chalcopyrite, sphalerite, galena, and pyrite, the

[1] L. Janin, Jr., "Mineral Industry," 1890, p. 203.

latter predominating, in a gangue of quartz and altered country rock. The gangue amounts to about 23 per cent of the ore, and consists mainly of silica. The deposit is regarded as a bedded vein, as it conforms in strike with the slates. An average sample taken by the government geologist on the 400-ft. level, and analyzed in the state laboratory, gave the following composition:

Gangue	23.70	Alumina	1.38
Metallic iron	17.75	Lime	0.40
Zinc	14.50	Magnesia	0.65
Copper	1.10	Gold	1 dwt. 12 gr. per ton.
Lead	8.04	Silver	2 oz. 8 dwt. 12 gr. per ton.
Lead sulphate	0.32		

The mine is 600 ft. deep, and is profitably operated despite the low grade of the ore, since pyritic smelting is practiced, and the remarkably low figure of $3.58 per ton is said to cover all mining and smelting costs.

Extraordinarily rich lodes are said to have been found in the Orange Plains, some 20 miles west of Dandaloo, in 1905. The ores are carbonates, and are opened for some 500 ft. along their course in the Mount Royal and Underlay mines, showing 5 to 6 ft. of good secondary ores at a depth of 190 ft.

Queensland

Queensland was formerly an important producer of copper, and still has several producing mines, though from an economic standpoint several of the properties have proved rather difficult to handle. The Chillagoe company's mines with the New Moonta mine, belonging to the Queensland Copper Company, and the Mount Garnet mine, belonging to the Freehold Copper Company, are the most important producers. The total production of Queensland for 1903 amounted to 4916 tons, of which the New Moonta mine alone produced 1365 tons, with 1309 oz. of gold and 70,760 oz. of silver as by-products.

The copper production of Queensland for 1905 was 1756 tons.[1] The relative importance of the different fields is shown by the following table giving the output of each field for 1905: —

Charter Towers	1¼ tons	£96
Cloncurry	65½ tons	4902
Gladstone	63½ tons	4673

[1] *Australian Mining Standard*, February 14, 1906, p. 158.

Heberton	1190	tons	£87,872
Kelkivan	¾	ton	53
Mount Morgan	671	tons	5009
Rockhampton	3	tons	214
Stanthorpe	29¼	tons	2169
Tennergering	336	tons	24,849
	1756¾	tons	

The Mungana mines yield both lead and copper ore, rich in silver. The Mount Garnet smelted 72 tons copper ore, giving one ton copper and 216 oz. silver. The furnaces ran but 18 days in the month.

Recent developments in the Mount Morgan gold mine, Queensland, for a long period the greatest gold mine of the world, show that the ore-body, slightly cupriferous at present depths, grades into copper ore in depth. Extensive borings with a diamond drill have revealed the presence of large bodies of gold-copper ore carrying 3½ per cent copper and 8 dwt. of gold per ton.[1] The product for July, August, and September, 1906, was 1027 tons of copper.

In the Chillagoe district there are numerous deposits of copper in carboniferous limestone, the deposits forming chambers associated with fissures. The New Chillagoe Railway and Mining Company built a railroad into this section and operated for a short time, but the ores proved so low-grade that the company was not able to earn interest on its bonded indebtedness. The production was 2191 tons in 1903.

The Hampden mine, in this same district, was active in 1901, shipping 431,692 lb. of 36.5 per cent copper ore. The deposit is an impregnation, with thin seams of chalcopyrite in a belt of vertical slates. It is, therefore, a bedded deposit. Above water level the lode consists of kaolin carrying nodules and masses of ore, mainly glance and red oxide, down to a depth of 70 ft.

The Mount Garnet lode, previously mentioned, is 60 ft. wide, and the outcrop has been traced for three-quarters of a mile. It is also a bedded lode.

The copper deposits of Cloncurry, in northern Queensland, are impregnations of green carbonate along lines of bedding usually near quartzites, or are small lenticular deposits in the folds or along the bedding planes of schist and shale. The Mount Elliot mine is the best developed. According to Kitchener,[2] the district is difficult of

[1] *Engineering and Mining Journal*, January 5, 1907, p. 47.
[2] Rutherford and Kitchener, *Mining and Scientific Press*, October 17, 1906, p. 583.

access, has a bad climate, lacks timber or water, and has no
fined deposits with definite walls.

Western Australia

Copper mining is as yet an unimportant feature of this state.
occur quite plentifully, especially in the northern districts; bu
ores carry little or no precious metals, and owing to the lack o
portation facilities, ores worth less than $40 per ton do not pay
mining is not an important industry. The production comes f
Mount Malcolm and Phillips River districts, the output for 19
20,526 tons of ore, and the total output to 1903 being 48,526 ton
value, in round numbers, of $1,300,000.[1] The ores occur in
veins of the usual type, and also in impregnations and stock
schists and porous sandstones, the deposit being adjacent to
masses and connected with veins. The state purchases cop
with a view to erecting a state mill in the near future. The onl
described in detail is the Avino. As shown in the accompanyi
(Fig. 58), a copper vein traverses granite and the sandstones in

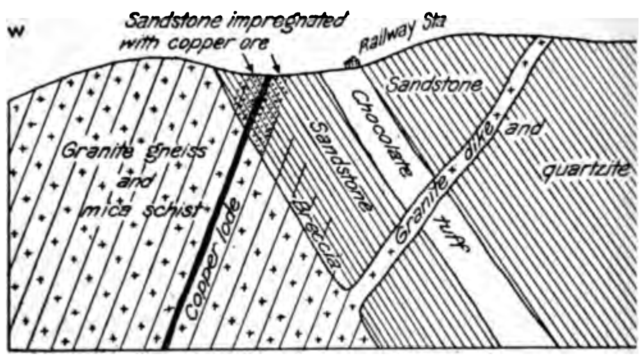


FIG. 58.—SECTION ACROSS AVINO COPPER DEPOSIT, WESTERN AU

therewith. Where the copper vein passes through the contac
has impregnated the standstones with ore. The jointing of the
extends a short and somewhat irregular distance into the
sandstones, and it is along these joints that the solutions have pe

[1] A. G. Maitland and C. F. V. Jackson, "The Mineral Production of We
tralia up to the End of the Year 1903." *Bulletin* 116, Geological Survey o
Australia, pp. 53-55.

Tasmania

The Mount Lyell mines of Tasmania are the most important copper deposits of the antipodes, and the Mount Lyell is one of the most successful mines of the world. The Lyell district is in the western mountainous part of the island, 28 miles by rail from Strahan, the nearest seaport, and at an elevation of 1200 to 1400 ft. above tide. The

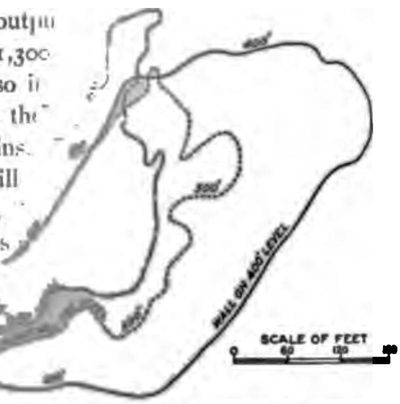
FIG. 59.—INDEX MAP, SHOWING LOCATION OF MT. LYELL, TASMANIA

rainfall is heavy, averaging 116 inches a year. The vegetation is dense, with thick scrub and many peat bogs, and the topography is rugged; so that the development of the district was attended with unusual difficulties. The principal deposit, known as the Mount Lyell, is a great lenticular stock of cupriferous pyrite occurring at the contact between chloritic or sericitic schist (more or less impregnated by copper sulphides) and a firm conglomerate carrying layers of quartzite, these sedimentary rocks being of Silurian age. This contact is traceable northward for several miles, and is marked by large hematite outcrops, and at a few points by workable orebodies, mainly of rich, silicious bornite ores, though in general the contact is barren. A number of cross faults have shifted the contact and interfered with its continuity (see Fig. 63). The access, has a bad climate, lacks timber or fined deposits with definite walls.

impregnation is ... that the con- ... schists. The ...ndary enrichment ores ...ter, consisting mainly ...semble closely the ores of ...orebodies found on the

WESTERN AUSTR

Copper mining is as yet an unimportant ... occur quite plentifully, especially in the ... ores carry little or no precious metals, ... portation facilities, ores worth less than ... mining is not an important industry. Mount Malcolm and Phillips River di... 20,526 tons of ore, and the total outpu... value, in round numbers, of $1,300... veins of the usual type, and also i... schists and porous sandstones, the... masses and connected with veins... with a view to erecting a state mill... described in detail is the Avino. (Fig. 58), a copper vein traverses...



...SHOWING CONTOUR OF OREBODIES AT ... FROM COMPANY'S MAPS)

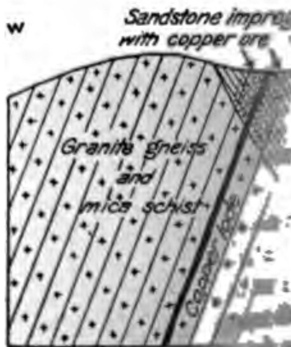


FIG. 58. SECTION ACROSS...

...gular, lenticular stock, a cross-section of ... vertical cross-section through the middle ... cross-section on any other line would be ... dimensions of the orebody are on the No. 4 ... and 650 ft. long and 270 ft. wide. The ... for a distance of 730 ft. below the sur- ... show it to extend to far greater depths.

therewith. Where the ... average 2.35 per cent copper; but a large has impregnated the ... per cent copper, though, on account extends a short and ... usefulness in mixing with the higher- sandstones, and it is a ... deposits, this ore is all available for ... schist and does not penetrate the ... movement has occurred along the con- ... the secondary ores which make the

[1] A. G. Maitland an... tralia up to the End o... Australia, pp. 53-55.

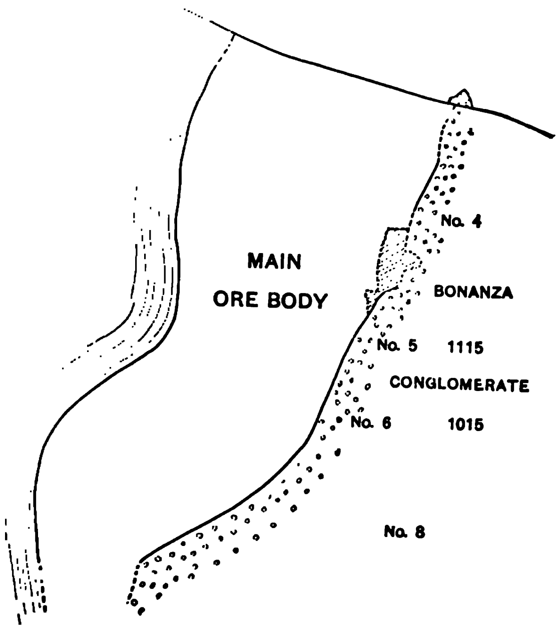
:emarkable for its yield,
.l pyrite ore carries:

.5	Alumina............ 2.4
.35	Sulphur............46.5

ore, carries:

...1.5	Alumina............ 6.3
..5.3	Sulphur............30.0

other orebodies and of the schist run
.ul from 5 to 10 per cent iron, running



.:. - VERTICAL CROSS-SECTION OF MAIN OREBODY, MT. LYELL. (MODIFIED FROM DALY)

:om 10 to 17 per cent alumina. The Mount Lyell ore is at times laminated, sometimes shattered, and incloses layers of hard chert and jasper near the footwall. The deposit is very dry in its lower part, the small amounts of water in the upper levels being quite acid. The schists carry pyrite in certain bands, and in places this rich enough to pay for working. It is inferred from th tact orebodies have derived their ore contents from tl Mount Lyell orebody is mainly pyrite; but secondary occur about its edges, which are silicious in character, c of bornite in a gangue of quartz, and which resemble c the Tharsis, North Lyell, and other silicious orebodi contact farther north.

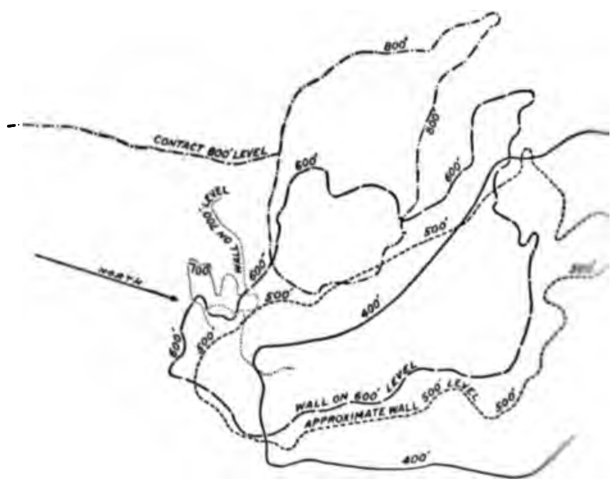


FIG. 60. – LEVEL MAP OF MT. LYELL, SHOWING CONTO VARIOUS LEVELS. (FROM COMPANY'S

The Lyell orebody is an irregular, lenticular s which is shown in Fig. 60. A vertical cross-sect is also given (Fig. 61), but a cross-section on a less regular. The greatest dimensions of the o level, where it is irregularly oval, 650 ft. long orebody has been developed for a distance of face, and diamond-drill holes show it to exte The outputs for several years average 2.35 p portion of the orebody carries only .66 per cent of the low working expenses and its usefulness grade silicious ores from the other deposits. working. The deposit occurs in the schist conglomerate, and it appears that movemen tact, forming open spaces filled by the sec been unprofitable, except where they are mined as metal-bearing fluxes for admixture with the basic ores of the sulphide lenses. The fahlbands are widely distributed through the schists, but occur especially along the course of the chief transverse faults. They are impregnated with pyrite fahlore, copper pyrite, and bornite. These minerals are sometimes sparsely disseminated through the ordinary schist; sometimes they occur in silicious schists, forming the silicious copper ores; and sometimes are segregated in bands of low-grade material, valuable as a flux. At the reserve tunnels, where the ore is mined for the latter purpose, the better ore occurs in bunches varying from 1 to 4 ft. in thickness, and about 6 ft. in length, these bunches being separated from one another by several feet of crushed and brecciated barren schist. The ore bunches were traced by prospecting for a vertical distance of 110 ft., appearing to form a series of chimney-like shoots along a fault plane running parallel to the foliation of the rock. At another locality there is a large deposit of mineralized schist traversed by many seams and bands of pyrite, the sulphides not being segregated in bunches, as at the former place.

The genesis of the Mount Lyell deposits has been very thoroughly investigated by Gregory,[1] who arrives at the conclusion that they are metasomatic replacements in and of crushed material found along fault lines. The so-called swamp theory is disproved by the structural geology. The contact theory can only be used in its widest sense; for the great pyritic masses appear to be indirectly due to the fracturing of the schists, where they have been crushed against the harder masses of conglomerate. Microscopic evidence shows that the pyritic minerals of the schists are truly secondary. Both in these rocks and in the main orebodies the evidence shows that the pyrite has been formed metasomatically by the replacement, molecule by molecule, of the original rock by pyrite. The minerals present in the ore masses have very sharply defined crystal outlines, and are often built up as loose skeleton crystals, showing that they have been formed *in situ* after the foliation of the schists.

The relation of the orebodies to the faulting is quite intimate. The most striking geological feature of the Lyell field is its great fault system, and an examination of the distribution of the ores showed that they are in every place closely connected with the faults. These faults were not all made by the same earth movements, but were formed at different dates, extending over a considerable period of time. The deposition of

[1] *Australasian Mining Standard*, July 12, 1905; "The Mt. Lyell Mining Field, Tasmania." *Transactions* Australasian Institute of Mining Engineers, vol. x, 1905, p. 26.

the ores was probably going on simultaneously with the development of this complex fault system; hence in one place the ores have been earlier than the faults, and elsewhere they are later. The two main orebodies of the field occur where masses of the schists have been nipped in the reëntering angles between great hard blocks of conglomerate. The Mount Lyell mine has been developed in schist which is bounded on the east by the Great Lyell fault, to the south by a later cross fault, throwing the Great Fault to the west, and is bounded below by a thrust plane which has shifted the lower part of the Mount Lyell orebody to the west, leaving it isolated as the buried pyritic mass of the South Lyell mine.

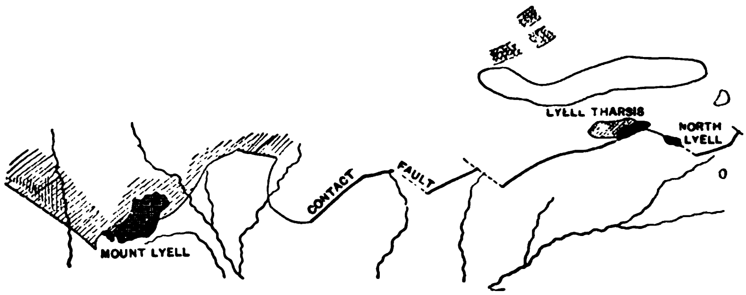


FIG. 63.—MAP SHOWING GEOLOGICAL RELATIONS OF OREBODIES, MT. LYEL
(MODIFIED FROM GREGORY)

The relations of the Mount Lyell ores to igneous rocks is not clos The igneous rocks of the vicinity are pre-Silurian, and cannot have bee connected with the formation of the Mount Lyell ore. The depos is regarded as due to tectonic and not igneous action. The meta were probably carried into the rocks in hot alkaline waters; for th primary ores are sulphides. The gangue minerals are quartz an barite, the latter of which may have been introduced as bariu sulphydrate, subsequently oxidized to barium sulphate and thus pr cipitated. The hot solutions were plutonic or deep-seated water probably alkaline in character. Their heat was presumably ge erated by the formation of the Great Mount Lyell fault. The waters carried sulphates of iron and copper, and some silver and go in solution, and deposited their contents along their channels by reli of pressure and cooling. When the solutions rose along simple fa lines in the schist, they produced the widespread fahlbands of miner ized schists. In other places, owing to the intersection of cross faul the rocks were completely shattered, and fault fissures ran in directions through blocks of rock. In these cases mineralizing solutions have permeated the rock, attacked and replaced the fragments by pyrite, and formed great masses of pure ore; hence the chief pyritic masses occur only where the schists have been completely crushed and shattered by intercrossing faults.

The ores contain very little arsenic and little antimony, fahlore and enargite occurring only in the secondary enrichments. There is no crustification; and the lamination of the pyrite observed in one place is presumably due to the replacement, layer by layer, of varying material.

The pyritic ores are remarkably free from gangue, uniform in composition, and show a concentration of the precious metals on the foot-wall side of the orebody.

The contact line is easily discovered, is generally marked by gossan, and has been searched with great care and heavy cost: but most of it has proved barren. Gregory offers the following directions for prospecting:

(1) The fahlbands may be expected to occur widely distributed through the schists, especially where the country has been much disturbed. They will occur only in the schists, sometimes outcropping on the surface as bands of pyritized rock, in other places showing by ironstone gossan. Their value is comparatively little, and only the largest pay to work as metal-bearing fluxes.

(2) The second type of the Mount Lyell ore deposits is that of the great ore masses. It includes two varieties, the acid ores of North Mount Lyell and the pyritic ores of Mount Lyell. These ores have been formed where the schists have been shattered in all directions and rendered permeable by mineral-bearing sulphurous solutions. The distribution of the pyritic masses and of the silicious bornite ores have certain features in common, for they have both been formed where the Great Lyell fault has been crossed by transverse movements. Prospecting should be directed to an examination of existing gossan masses.

North Dundas District. — The importance of the Lyell properties has overshadowed that of several other deposits, mostly low-grade, of other types found elsewhere in Tasmania.

As noted by Waller,[1] several types occur in North Dundas, namely:

1. Axinitic and pyritic copper deposits (Colebrook type), allied to the tin deposits.

2. Tourmaline gol -copper veins (Mount Black type).

3. Pyritic copper deposits of mixed complex sulphides (Mount Read type).

[1] *Report* Geological Survey of Tasmania, 1904.

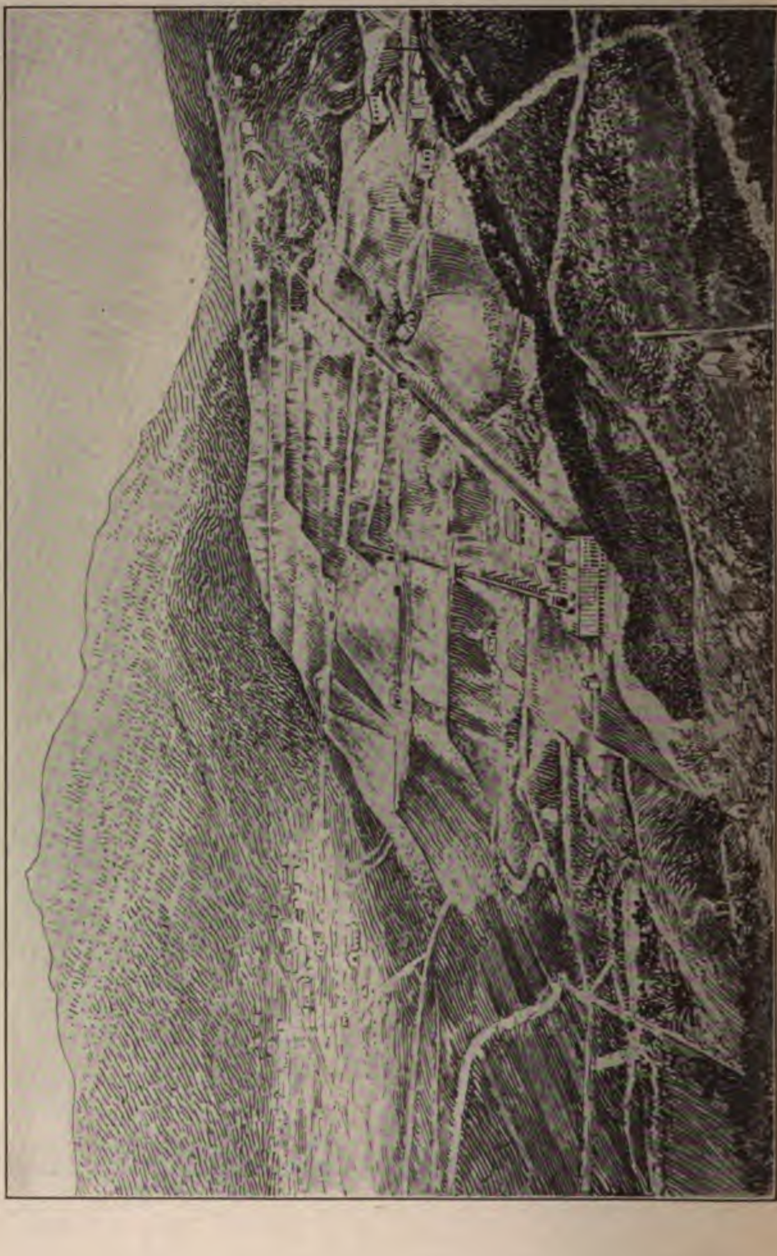


FIG. 64.—SKETCH OF MT. LYELL MINE. (DRAWN FROM PHOTOGRAPH)

4. Fahlore veins (sideritic, Curtain-Davis type).

The first-named is as yet of little economic importance.

Axinitic Deposits.—In hard, fine-grained, laminated shales and slates, with beds of impure limestone or calcareous shale. No acid igneous rocks near by, but a gabbro-serpentine belt is near at hand. Orebodies are parallel, run east and north, dip steeply west, are traceable for 550 to 700 ft. on course, and vary from 10 to 60 ft. thick. The ore is usually banded with alternate bands of axinite and actinolite, but it also occurs massive and in irregular patches in country rock. Axinite (borosilicate of alumina and calcium) is abundant, and is associated with and occurs in pyrrhotite and chalcopyrite. Actinolite (silicate of lime, magnesium, and iron) is abundant both in orebodies and in wall rock. Vugs contain datolite and danburite (silicates of boron and lime). Quartz is scanty. Of metallic minerals pyrrhotite is most abundant, forming large bands and masses up to 10 or 15 ft. thick. Chalcopyrite is widely distributed, both in massive pyrrhotite and in the axinite. Massive arsenopyrite forms veinlets 6 to 8 in. thick. The deposits are practically unoxidized. Several deposits occur separated by bands of slate, the rock being often mineralized and merging into ore. Tongues and branches of axinite and actinolite run out into the wall rock.

The orebodies originated by a replacement of impure limestone, due to hot ascending solutions containing boron compounds, emanating from a granite magma during the process of consolidation, and following planes of stratification and fissure. The following table shows the composition of six samples of the low-grade ore of the deposits:

	1	2	3	4	5	6
Copper, per cent	1.36	1.67	2.9	1.6	3.06	3.4
Silver	9 dwt.	17 dwt.	1 oz. 1 dwt.	9 dwt.	16 dwt.	18 dwt.

The difference in the metallic contents of the first two classes of deposits may be due to differences in the levels (or, what is the same thing, differences in the distances from the cooling granite magma) at which the original deposits were formed. Or, it may be due to differences in the composition of the rocks, some being more favorable for deposition of copper ore, others for zinc and lead.

Observations by Waller show that zinc-lead ores lie above and pass into copper in depth. There is, therefore, much reason to believe that a zone of copper ore (primary) may be found beneath the zinc-lead sulphide zone.

It seems probable that the process of ore deposition has passed through a number of phases, deposits of different types being formed at different periods and at varying distances from the seat of the eruption.

Tourmaline Gold-copper Deposits. — These occur in light-colored argillaceous schists, with bands of dark slate and occasionally of quartzite and silicious schist. Bands of soda-syenite-porphyry (keratophyre), now schistose, are common.

These deposits are small fissure veins in keratophyre or its contact rocks. They have well-defined walls, crushed structure. The vein filling consists of quartz, tourmaline, fluorite (locally abundant), pyrite, copper pyrite, and a little arsenopyrite, bismuthinite, and wolframite. There are associated replacement deposits near by.

Pyritic Deposits. — The deposits are large pyrite veins containing small shoots of fahlore. The wall rock is largely replaced by pyrite. Much pyrite means little siderite, and the reverse. Ores carry chalcopyrite, arsenopyrite, blende, etc., as polybasite.

Fahlore Deposits. — Sideritic fahlore deposits occur in Tasmania in slates, graywackes, breccias, and conglomerates, and quartz porphyry.

The orebody of the Tasmania Copper Company consists of a band of iron and copper pyrites deposited as a replacement of the country rock along the line of a fault fissure. The footwall schist is heavily impregnated with pyrite, and carries barite. Pay shoot 100 ft., thickness ½ to 4 or 5 ft. Ore carries 8.76 per cent copper, 1.75 oz. per ton silver, 32 per cent iron, 18.48 per cent silica, and 37.95 per cent sulphur.

UTH AMERICA

\ndean mining region of South
itry running from the equator to
great ranges of the Andes with an
the east lie the great forests of
entine, to the west a narrow strip of
.. mostly a dry and arid desert. The
allel with the shore line, rising abrupt
to hights unknown in North America.
gular, with numerous connecting ranges.
ble width, is in Peru, 12,000 to 16,000 ft.
declines southward. It is mostly an arid
t is cold and almost uninhabitable in Peru,
grass and bogs, whose verdure brightens the

the Andean region are of two distinct classes;
copper ores and (2) those of copper alone.
g been regarded as more valuable for silver than
ielded important amounts of the latter metal.
narrow veins in or adjacent to bodies of augite
desitic rocks, or of diorites, intrusive in upturned
es. They are found chiefly in the higher parts of
pper, at distances of 30 to 100 miles from the coast.
un north and south, have a silicious jaspery or quartz
some calcite. The ores are complex sulphides, with
nic and sometimes lead and zinc.
s is especially abundant in the coast Cordillera. The
er and often have gold values, but are without arsenic,
nganese. The gangue is crystalline quartz, not jasper,
rbonates. The outcrop is often gossan, covered, and

It seems probable that the process [redacted], silicates, and oxy-
a number of phases, deposits of differe
periods and at varying distances [redacted] region of the continent,

Tourmaline Gold-copper [redacted] and in Brazil, but
argillaceous schists, with [redacted]
and silicious schist. Bands of so
now schistose, are common. [redacted]

These deposits are small fissure [illegible] Republic has furnished a
rocks. They have well-defined [illegible] but the amount has been
filling consists of quartz, tourmalin [illegible] copper-bearing belt of that
copper pyrite, and a little arsenop [illegible] the western border of the
There are associated replacement [illegible] forming the eastern part of the

Pyritic Deposits. — The dep [illegible] complex sulpharsenides or
small shoots of fahlore. The [illegible] extraordinarily high values in
Much pyrite means little siderite [illegible] argite ($CuAs_4S$); but the allied
copyrite, arsenopyrite, blende, [illegible] accompanies the former, differing

Fahlore Deposits. — Siderite [illegible] copper, with 3 or 4 per cent of ar-
slates, graywackes, breccias, [illegible] region. Covellite, bornite, cyano-

The orebody of the Tasmani [illegible] silver and copper) also occur,
iron and copper pyrites depo [illegible] ango (variety humangite), near
along the line of a fault [illegible]
pregnated with pyrite, and [redacted] are extraordinarily rich in
½ to 4 or 5 ft. Ore carries [redacted] this section is penetrated by a
32 per cent iron, 18.48 per [redacted] almost to the base of the Andes,
[redacted] the Cordillera and connects
[redacted] of the mining industries
[redacted]

[redacted] now worked commercially, are
[redacted] city of Chilecito. This town is
[redacted] of the railroad which runs to ports

[redacted] principal mines occur, lies on the
[redacted] district being from 10 to 15 miles
[redacted] an area of about 8 by 15 miles.
[redacted], with arid and steep mountain
[redacted] valleys. The Famatina district
[redacted], Cerro Negro, and other mineral

[redacted] gîtes mineraux métallifères."

FIG. 65. – BLEICHERT ROPEWAY, ARGENTINA

[illegible] metamorphic Silurian slates, cut by intrusive [illegible], and traversed by an intricate network [illegible] running in almost every direction and of vari[illegible] in bulges and shoots. The gossan of these veins [illegible] was worked for the precious metals only. [illegible] carbonates and oxides occur, and beneath them the [illegible]

[illegible] subdistrict, and that of Cerro Negro to the south[illegible] culminate in the Espina Peak, which is 18,970 ft. [illegible] lie to the northeast of this peak at altitudes of [illegible]

[illegible] that of Upulungos, in which the veins vary from [illegible] and average 2½ ft. across. The veins run north[illegible] northwest at 70 deg., and show an ore shoot [illegible] The rich ore formerly mined had 15 per cent copper, [illegible] over an ounce in gold to the ton. The main [illegible] into the ranges north and south.

[illegible] has spent £170,000 on an aërial tramway to carry [illegible] where it will be smelted.

[illegible] mines of this district, and, indeed, of all Argentina, [illegible] Famatina Development Company, Ltd. This cor[illegible] control of a large tract 2400 by 2000 meters [illegible] the Mejicana district. The contracts with the Gov[illegible] output of 400 tons per day. The smelting works [illegible] at Patyaco, 21 miles from Chilecito; but, as [illegible] connects Chilecito with these mines and the other [illegible] district, it is evident that the main center for [illegible] treatment will be on the Famatina river, near Chilecito. [illegible] were formerly treated in three small establishments, [illegible] reverberatory furnaces, matted and reroasted two [illegible], and finally shipped by mule-back to the [illegible] to Hoskold, the former cost of mining, treatment, [illegible] including administration expenses, was $10 per [illegible] matte was worth $18 per 100 lb. in Liverpool. [illegible] have already been erected at Nonogasta, a few [illegible] Chilecito, and at Santa Florentina; but the Devel[illegible] expected to erect a large and complete smelting [illegible] future. The production of these six mines from [illegible] April, 1904, was about 1000 tons of ore, averaging [illegible] 2.70 per cent silver, and 0.0169 per cent gold, from

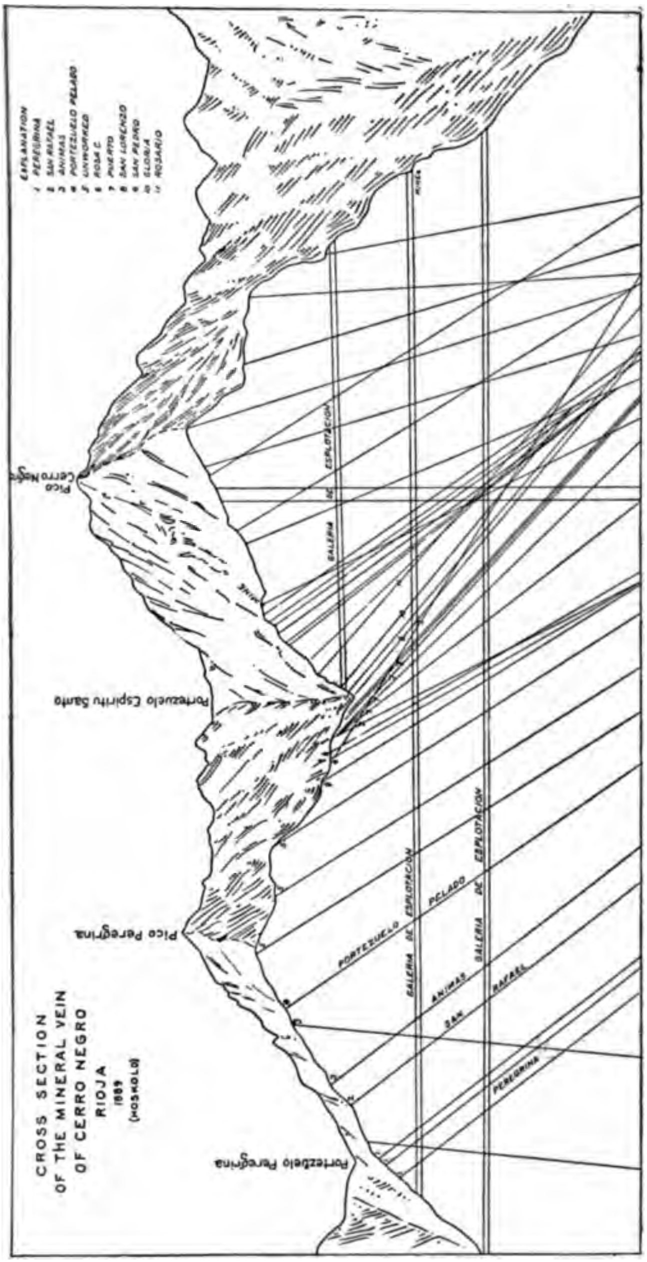


FIG. 66.—CROSS-SECTION OF VEINS OF FAMATINA DISTRICT, ARGENTINA. (HOSKOLD)

which matte was produced containing 162,775 lb. of copper, 568 kilos of silver, and 15 kilos of gold. The ores from the Upulungos mine are at present low-grade, averaging but a little over 3 per cent copper; those from the White Lode mine are but a little higher, but as the ores carried high silver and gold values they were profitably worked.

An exhaustive examination by John Taylor & Sons shows that the vein formation is extensive and that there are large amounts of ore. According to this report, the veins are irregular, varying from a few inches to as many feet, and the ore itself varies considerably in value. The ore over an extensive area has an average of 3 to 4 per cent copper, $4 to $5 in gold, and 10 to 15 oz. of silver per ton.[1]

In the province of Catamarca, to the north of this region, the mines are not at present workable, as the railroad has not been extended to this section. The mines all occur in the mountain area, where barren peaks are separated by furnace-like valleys filled with pumice dust. The most famous mines are in the Cerro de Capillitas, a range formed of gneiss, granite-porphyry, and trachyte-porphyry. The veins cut through both the trachyte and the granite, and carry the same ores already mentioned, with gold and silver values. The most famous mine is the Restauradora, which has been opened by a cross-cut tunnel 6477 ft. long. The mine was first opened in 1860, and has been intermittently worked ever since. It now belongs to the Capillitas Mining Company, which also controls a number of other properties in the same district. Assays of samples, collected by Hoskold, showed 26 per cent copper, 10 per cent iron, 3 per cent zinc, 0.4 per cent bismuth, 0.3 per cent lead, 7.3 per cent arsenic, 0.6 per cent antimony, 1 per cent carbonate of lime, 5.7 per cent silica, and 33.4 per cent sulphur, the ore consisting largely of chalcopyrite, tetrahedrite, and pyrite, with accessory blende, galena, etc. The enargite, copper glance, and famatinite existed in the higher parts of the veins immediately beneath the carbonates, but diminished in quantity in depth. Where the vein is low in copper, it usually carries considerable galena and blende. One ore shoot, developed in the vein at 133 yd. from the mouth of the tunnel, was 84 ft. long, and had a streak averaging 49½ in. thick of pure gray copper, carrying high values in gold. The gangue consists of quartz and dolomite, with more or less pyrite. The ore is smelted at Visvis.[2]

[1] *Mining Journal*, October, 1905.

[2] Official report upon the mines, mining, metallurgy, and mining laws, etc., of the Argentine Republic, by H. D. Hoskold, published by the Minister of Agriculture, Commerce, and Industry, Buenos Ayres, 1904.

Other mines occur in the province of Buenos Ayres and other parts of Argentina, but they lack the high values in copper and the precious metals characteristic of the Andean region. The future copper production of this great republic will undoubtedly be largely from along its western border.

Bolivia

The copper production of Bolivia comes entirely from the Coro Coro district, province of Pacajes, in the department of La Paz. The district is in the middle of the Titicaca basin, a few miles south of the lake of that name. The mines are in the Serrania de Coro Coro-Chacarilla, which form a low, isolated mountain mass rising like an island above the level desert plain of the Bolivian plateau, that is inclosed between the Andes on the east and the coastal range or Cordillera Real on the west. The Andes consist of Jurassic limestones and shales, etc., cut by numerous intrusive masses of igneous rock of Tertiary age. The coastal Cordillera consists of Paleozoic schists, with numerous porphyry and trachite dikes. The intervening valley has been filled up with recent sands, clays, etc., and the only rocks outcropping are those at Coro Coro. These consist of red shales, conglomerates, sandstones, and clay, with calcareous ferruginous cement. Gypsum and rock-salt occur in seams and stringers. The town is in a deep-cut valley on the west side of the mountain. It is 40 miles by wagon-road south of Viacha, a station on the La Paz railway that is 550 miles from the seaport Mollendo.

The copper-bearing beds consist of ashen gray, fine-grained to coarse-textured sandstones and conglomerates, with blue, green, and black staining. The uppermost beds are grits holding seams of copper ore and stained by it, but too poor to pay for working. These light-colored copper-bearing rocks are capped by the red sandstones. The pebbly conglomerates of the series are also impregnated with copper. The beds dip westward at 70 to 80 deg. and are broken by a fault that runs north and south with the strike, the strata dipping steeply away from the fault on both sides of it. On one side the pebbly copper-bearing conglomerates are underlain by the Buen Pastor lode, a fine-grained reddish-brown sandstone, devoid of ore except in the green or the gray patches. This bed is underlain by grits and fine conglomerates down to the ore bed, called "Veta de Rejo." Still lower in similar rocks is the Veta Remacoia, with native copper disseminated through a coarse grit in grains, irregular lumps, or plates. These ore-bearing beds rest upon an immense thickness of fine-grained and crumbly red sandstone. East of the fault there is an immense thickness of the same red, shaly sandstones, dipping east 55 deg., with metallic copper in beds called "ramos." Five of these are shown in Fig. 67, but there are many more. The dip is 80 deg. near the fault, but lessens away from it.

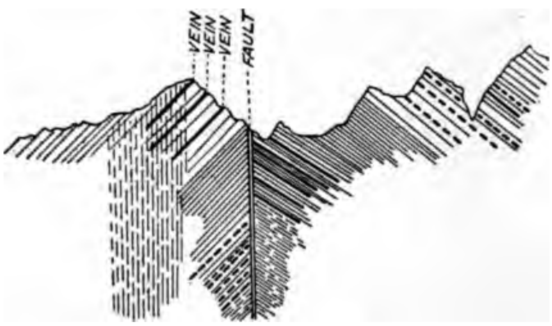


FIG. 67 — CROSS-SECTION OF CORO CORO VEINS, BOLIVIA. (FORBES)

Most of the ore-bearing beds average from 2 to 6 ft. in thickness, the Buen Pastor having, however, a thickness of 42 ft. and the Veta Dorado showing 3 to 60 ft. of $3\frac{1}{2}$ per cent ore. The ores are seldom continuous for any great distance, but are scattered through the metalliferous sandstone in irregular patches or spots of white or greenish color, full of small grains of metallic copper, the color of these spots forming a strong contrast to the red of the rest of the bed.

The copper is mainly native; but arsenates and glance occur, especially in the deeper workings. Plant remains and bones, with the center filled with native copper, have been found. Domeykite (arsenic 28 per cent, copper 71 per cent) occurs; copper replacing calcite and shell showing a calcite center has been noted. These sandstones are 2000 ft. thick, and are copper-bearing for many miles south of the town of Coro Coro. Native silver occurs in many of the seams.[1] The mineralization is supposed to be due to solutions rising along fissures and percolating through these vertical beds of porous rock. The mines are dry below a depth of 500 feet or so.

The workable mineralized area, which is about a half-mile wide and 5 miles long, is owned and worked by five companies and some

[1] David Forbes, "Geology of Bolivia and Southern Peru." *Quarterly Journal of Geology*, 1861, vol. xvii, p. 41.

copper, 1½ per cent silver, 8 per cent lead, 16 per cent zinc, 2 pe
arsenic, 14 per cent iron, 23 per cent sulphur, and 24 per cent
The Huanchaca company is reported to have produced 3,000,c
of copper in 1902, and two firms, buyers and miners of ore fro
district, 3,419,200 lb.

Brazil

Deposits of copper ores occur in several of the mountainous sta
Brazil, the most notable being those of the state of Rio Grande de
In the copper districts of this state the upturned Jurassic sands

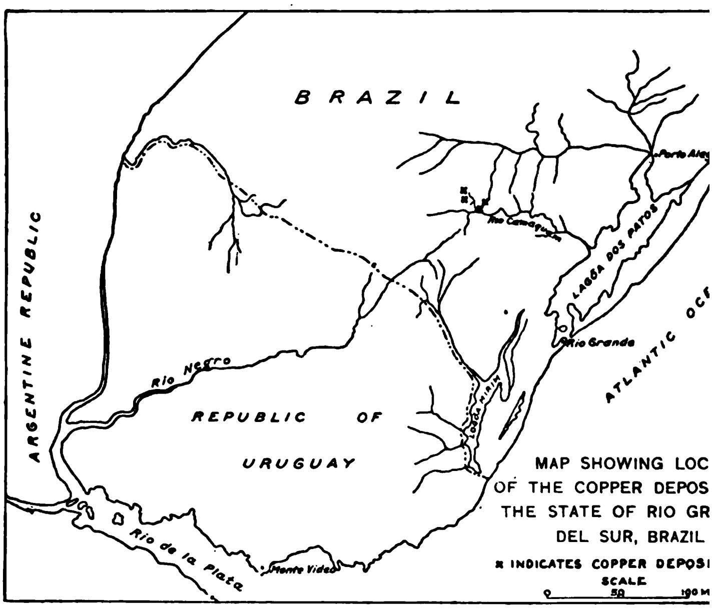


FIG. 69. — INDEX MAP OF SOUTH BRAZIL COPPER MINES

shales, and conglomerates forming the Serra Cacapava contain a
belt impregnated with copper, traceable for 72 miles along the
The ore consists of impregnations and veinlets of the green and blu
bonates. The principal workings are at Camaquam, where a B
syndicate, known as the Société de Mines de Cuivre du Camaquam
the principal properties. This syndicate, formed in 1900, has a
plete mining plant, smelter, and electric power plant. The ore

[1] Fuchs and De Launay, *op. cit.*

water level consists of glance in thin but well-marked veins. West of the town of Cacapava, near the Santa Barbara river, there are half a dozen mines working a belt of cupriferous shale that is 60 to 90 ft. wide. The bed has a southeast to northwest course, is nearly on edge, and lies

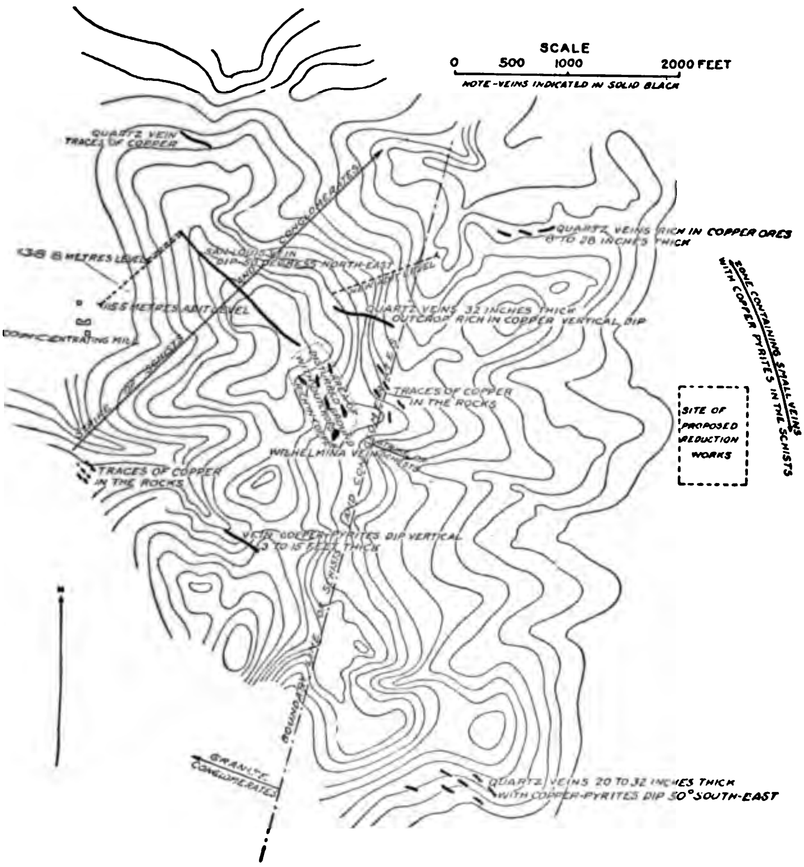


FIG. 70. — MAP OF THE COPPER MINES OF CAMAQUAM, BRAZIL

between sandstones and conglomerates. It contains silicates, carbonates, and some copper glance. The chief development is at the Primavera mine, where a shaft 100 ft. deep exposes ore said to average 6 per cent in copper, which on trial shipment concentrated 6 to 1 on a Wilfley concentrator, yielding 50 per cent concentrates. As yet none of the mines are productive.[1]

The copper ores from Brazil seen at the St. Louis Exposition included samples of glance from the Parana, in which the glance cements a breccia of silicious or quartzose schist.

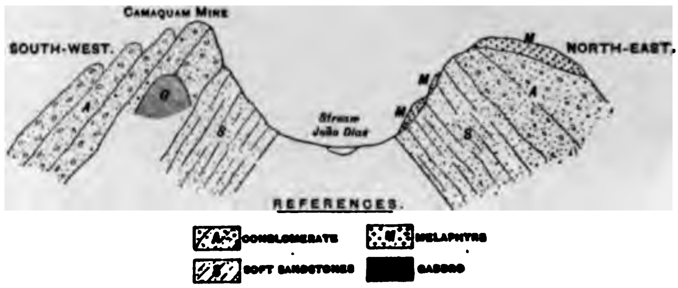


FIG. 71. — CROSS-SECTION OF CAMAQUAM MINE, BRAZIL

Bahia. — This state contains undeveloped copper deposits situated 50 miles west of Jaguarary, a station on the Bahia & St. Francisco Railroad. The property is now being explored by an English company. The copper occurs as carbonates impregnating hornblende schist, and averages 4 per cent copper.[2] At Paco Alegre Guraca there are beds of impregnated sandstone of great extent, lying near the Central Railway of Bahia.

Minas Geraes. — Numerous copper deposits occur in this province in the peculiar schist formations of that country. The ores consist of quartz schist, with bands and nodules of specular iron and copper carbonates, with layers of sericite. Some ores are brecciated, silicious, or quartz schist, cemented by glance. The ores are lean.

CHILE

From what is known of the number and extent of its deposits of copper, Chile is probably one of the richest countries of the world in this metal. It was formerly one of the largest producing countries, but the output has declined with the gradual exhaustion of the rich surface and secondary ores, until at present it is less than that of Japan or Australia. The

[1] Information from pamphlet on Rio Grande del Sur, published for St. Louis Exposition, 1904.

[2] See Francisco Ignacio Ferreira, "Dictionario Geografico da Minas do Brazil," Rio Janeiro, 1885.

rich ores of many districts are entirely gone, and the future production of the country must come from the low-grade deposits, which occur in great abundance, but can only be worked where railway lines are contiguous. Notwithstanding these conditions, 7106 registered copper mines, 427 silver-copper mines, and 120 copper-gold mines paid taxes to the Government mining offices in 1903. In 1902 there were 1124 working copper mines and 41 copper reduction works in operation in Chile.[1]

The country produced 30,229 tons of copper in 1904,[2] of which amount 15,603 tons went to England, 6371 tons to France, 2541 tons to the United States, and the balance to Germany.

The copper output is officially[3] given as follows:

1900	28,040,000 Kg.
1901	30,155,326 Kg.
1902	29,580,000 Kg.
1903	29,923,132 Kg.

Practically all the western provinces, from Tacna on the north to Santiago and Victoria on the south, contain copper mines; but the greatest number occur in the region tributary to Antofagasta, with the Coquimbo region second in the list.

The long stretch of country forming Chile is best discussed by sections, since, though relatively narrow, it extends for a length of 2270 miles from Peru to the southeasternmost end of the continent. Statistics of Chilean mines are usually given by provinces, but it is easier to group the mines under the name of the seaport from which shipments are made.

The two classes of copper deposits characteristic of the Andean region are well developed. The first class occurs in the coast range of northern Chile. They are quartz-pyrite veins cutting through various porphyries and diorites, syenites, and granular, basic, igneous rocks, the country rock often holding disseminated grains of ore. The ores contain bornite and chalcopyrite, with some gold; and silicates and carbonates of copper occur in the oxidized zone, but no native copper or oxide, and no calcite, manganese, and ore free from arsenic or antimony. In the weathered zone they show limonite, with carbonates, silicates, and oxychlorides.

The second type or class consists of north and south veins of com-

[1] List furnished by United States consul at Valparaiso, supplied by Jackson Bros., of that city. *United States Consular Report*, February 6, 1903, p. 2.

[2] *Mining Journal* (London), April 12, 1905, p. 179.

[3] "Estadista Miniere de Chile," 1903.

plex sulphurets of copper, with very little galena and blende, in augite porphyries. The gangue is red or green jasper, rarely with calcite. These veins occur at very high altitudes in connection with porphyritic intrusions in sedimentary (Mezozoic) rocks of the Cordillera, at 30 to 100 miles inland.

Immense deposits of low-grade cupriferous pyrite also occur (in the province of Coquimbo), but are not as yet successfully worked.

In the desert regions of Chile, oxidation often extends downward to depths of 800 to 1000 ft. or even more. The arid conditions have favored enrichment, not only at or near water level, but above it by a concentration and segregation into bunches of rich oxide and carbonate ores and of glance. It is these ores that have made Chile famous as a copper producer, and with their exhaustion the problem has been to work the low-grade sulphide ores which abound in the country. There is, however, but little information extant by which one may judge of the size of the deposits or the nature of these low-grade ores. To be workable, they must be large, and the ore easily concentrated.

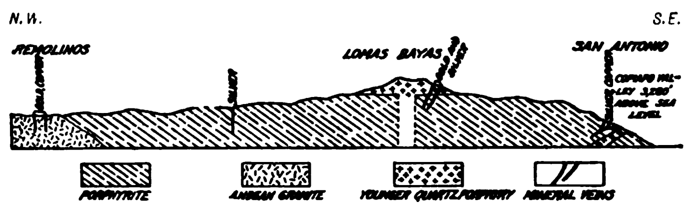


FIG. 72. — SECTION ACROSS REMOLINOS COPPER-BEARING DISTRICT, CHILE

The rich Chilean ores have been mostly smelted at the seaports, largely at Lota and Coronel, which are near the coalfields of southern Chile, and at Antofagasta, etc., in north Chile, the bar copper going mainly to England.

The principal copper port is Antofagasta, where smelting works have long existed. It is the export point for numerous Bolivian and Chilean mines. The principal copper mines of Chile are found in the coast range, between the above-named port and Valparaiso.

The most northerly port, Iquique, is connected by 299 miles of railroad with a mineral-producing region. The next important port to the south is Antofagasta, which has long had two copper-smelting works, one owned by an American firm, but now idle. The mines lie inland at Chuquicamata. A railroad runs from this point to Oruro, Bolivia, a distance of 575 miles.

Copiapó is the most important town of northern central Chile. The province of Atacama contains the Copiapó district, whose gold and silver mines were formerly worked on a large scale, and whose copper

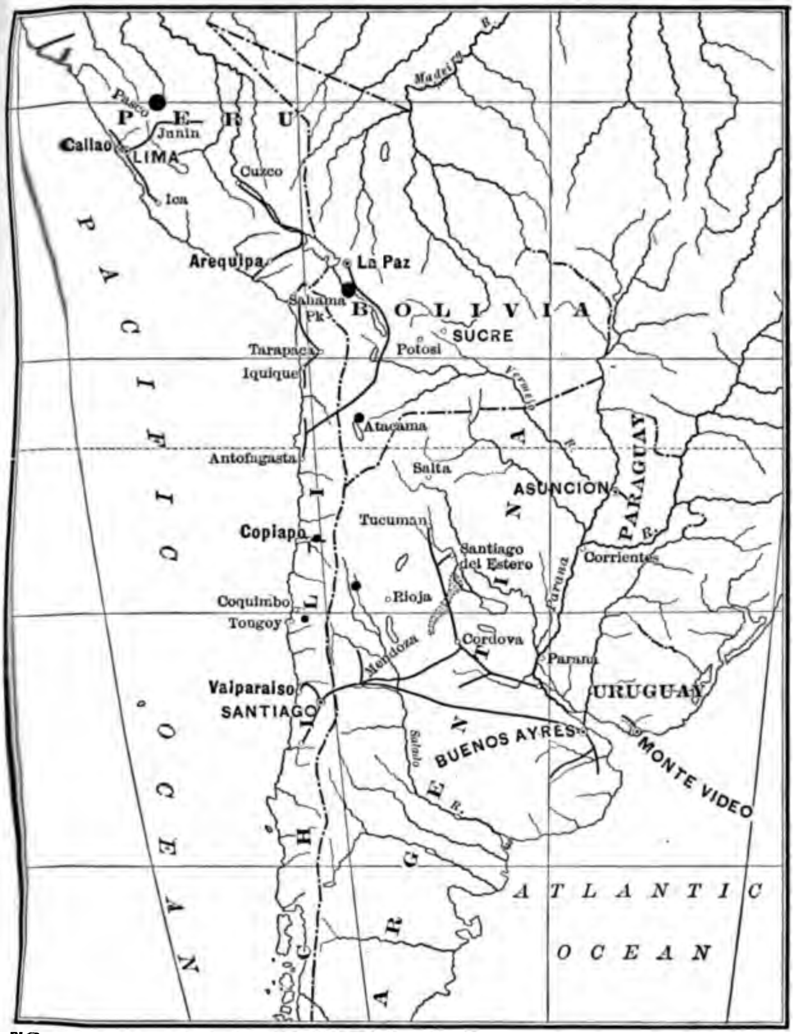


FIG. 73.—INDEX MAP, SHOWING LOCATION OF PRINCIPAL COPPER DISTRICTS OF THE ANDEAN REGION, SOUTH AMERICA

mines are still productive, there being 30 producing mines in 1903. Chañaral also contains copper deposits.

In Coquimbo 1398 of the 1883 mines that paid taxes in 1902 are registered as copper claims. In Copiapó there are 13 producing mines, two over 1000 ft. deep, one with a monthly output of 1200 tons, another 800, and another 300, the total being 2665 tons per month of ores averaging 16 per cent, none under 12 per cent being mined.[1]

Antofagasta Region. — Antofagasta is the smelting and shipping point for a number of copper mines in the interior, situated along the line of the railway that runs 575 miles to Oruro, Bolivia.

The Chuquicamata[2] district is 163 miles from the coast, at an elevation of 9000 ft. The district, which is 163 miles by rail from Antofagasta, produced 25,000 tons of 17 to 18 per cent ore in 1904, and since then has furnished the recent slight increase in the copper production of the country, the product of other mines decreasing or remaining stationary.

The mines are at the terminus of a branch railway line 12½ miles northwest of Calama, a station on the railroad from Antofagasta to Bolivia. Calama lies on the southern limit of the rainy region of the Bolivian plateau, the Atacama desert stretching southward and westward.

The copper-bearing area is a mile wide east and west and 2½ miles long north and south. It is a region of low, southerly sloping, undulating hills, cut by gullies. Granite, pegmatite, and syenite form the country rock, but are mantled by mountain débris.

The ores occur in north and south veins, except the important Veta San Lucas, running east and west. In the center of the field the rocks are shattered by a multitude of small copper-filled fissures (*llamperas*), believed to be the upward branches of veins. The ores carry oxidized copper minerals, mainly atacamite and sulphates, to 200 ft., where the black secondary ores occur and extend downward to the copper and iron pyrite found at 330 ft.

The Ponderosa mine yields 300 tons of 20 per cent ore monthly. The Zaragoza and Emilia are prospecting for sulphide ores. There are six principal mines, averaging from 300 to 350 ft. in depth. The ores occur in fissure veins in granite and rhyolite, decomposed and rotted for 200 ft. below the surface. Atacamite (oxychloride of copper) impregnates the rocks.

The Abra mines are 30 miles northeast of Chuquicamata, and 18 miles

[1] *United States Consular Report*, February 6, 1903.

[2] Carlos G. Avalos, "Asientos Mineral de Chuquicamata," *Boletin* of the Soc. Nacional de Mineria, 1901, ser. 3, vol. xiii, pp. 145–153. Nicanor Argandoña, *Mining Journal* (London), June 30, 1906, p. 854.

from the railroad, at an elevation of 10,000 ft. There is but one main lode, which cuts a mica hornblende granite. The unaltered ore is chalcopyrite in a quartz gangue, and averages 19 per cent. Annual production, 3600 tons. The vein is worked to 350 ft. in depth.

The Conchi district is near El Abra. The Lomas Bayas mine is 60 miles from the coast and 30 miles from the railroad, at 6000 ft. elevation. The ore occurs in two fissure veins in a biotite granite, and consists of gray copper and various oxidized ores with quartz gangue, the vein becoming impoverished in depth, passing from 250 ft. downward into pyrite, with disseminated molybdenite. The extreme depth is 550 ft. Annual production, 2400 tons of 15 per cent ore.

The Desesperado district, 46 miles northeast of Antofagasta, has two mines 262 ft. and 328 ft. deep respectively, which work narrow quartz veins in granite, and produce about 1000 tons annually of 18 per cent ore.

The Naguayan and Chacaya districts are near the last. The copper ores in the quartz veins do not extend below 80 meters (262 ft.), the percentage of copper diminishing rapidly in depth as the iron pyrite increases.

An attempt to work low-grade (2½ per cent) ores by wet processes is being made by the Société Industrie de Cobre de Antofagasta. The deposits are at Mantos de Varos, 2½ miles distant by tramway.

Copiapó Region.—This region lies about midway between Antofagasta and Coquimbo. The area tributary to Copiapó contains the Dulcinea mine (Copiapó Mining Company) of the Puquios district, the largest copper mine of all Chile, and some 40 or more mines that are steady but small producers. The Dulcinea mine is 2820 ft. deep, yields 600 to 700 tons of ore a month, and shows no sign of exhaustion.

The Descubridera group, in the same region, has recently been equipped with modern machinery.

The Amolinas mines, formerly the most important copper workings of the Copiapó department, are situated in the southernmost part of the Atacama desert region, 15 miles southeast of San Antonio, a station on the Caldera-Pacific Railroad. The mines are at an altitude of 7216 ft., at the upper end of the Amolinas gorge.

The region is composed of dark shales and hard sandstones identified as Jurassic (Oölite and Lias), cut and overlain by dikes, sills, sheets, and bosses of eruptive rock. Two great parallel dikes, 3000 ft. apart, run east and west, and form ramparts on either side of the valley. The northernmost is made of white rhyolite, porphyritic in depth, and full of irregular cavities, in part infilled by copper ore. A complex of

"ter" dikes; and the ore
and diabase porphyry.

earthy cuprite, and
tournonite, and malachite.
mile. The habit of the
lations in cracks and cavi
of their alkali being richer
carries 5 to 8 per cent copper
sight.

Tamaya mines, near Tongoy,
have been studied by Ha
a diorite, containing accessory
gular, from 6 to 10 ft. thick
gangue, though sometimes the
along the hanging wall. The
ll defined pay streaks and ore
arries tufts of free gold. The

300 ft., the Higuera, 950 ft.
p. At Chañaral, the Faltal
pper ores in depth.
to the railroad to Tongoy.
flooded, though the region was
workings extend to a vertical
the Lecaros tunnel, the great
cuts the rocks for 1¼ miles to

district are those belonging to
sing the Panulcillo group of
Panulcillo, 45 miles by railway
great lens of pyritic ore, running
2000 tons a month. The
and Inagotable mines,
miles by railway beyond Pa
ore. The production in 1904

C. ... vol. 81

Copaquire is 44 miles east of Challacollo, and 10,500 ft. above tide water. This newly rediscovered deposit of copper sulphate occurs in a granite *massif* at its contact with sedimentary rocks. The granite is altered and impregnated with chalcopyrite particles, and in the decomposed belts is spotted with blue chalcanthite, with associated gypsum and limonite. Both solid rock and talus carry 2.5 to 3 per cent of copper. The primary sulphides of this part of Tarapaca occur in acid eruptive rocks.[1]

In Tarapaca important discoveries have been made at Collahuasi, a point 13,120 ft. high, connected by a 54-mile branch line of the Onera-Antofagasta railway at Carcate. Three companies mined, in 1903, 5000 tons of ore, carrying 32 per cent copper, 2.3 grains gold, and 600 grains silver per ton.[2]

At Tres Punas, in Atacama province, there are copper ores in the garnet zones about quartz porphyry and limestone contacts.

In the province of Valparaiso, at the Cerro de Campana, the contact zone of garnet rock about diorite intrusions contains bornite and gold.

In Santiago province the Volcan Company at Catemu produced 2400 tons metallic copper in 1905. The Chilean mines have yielded many new and unusual copper minerals. Caledonite, a sulphate and carbonate of lead and copper, is one of those recently discovered.[3]

Ecuador

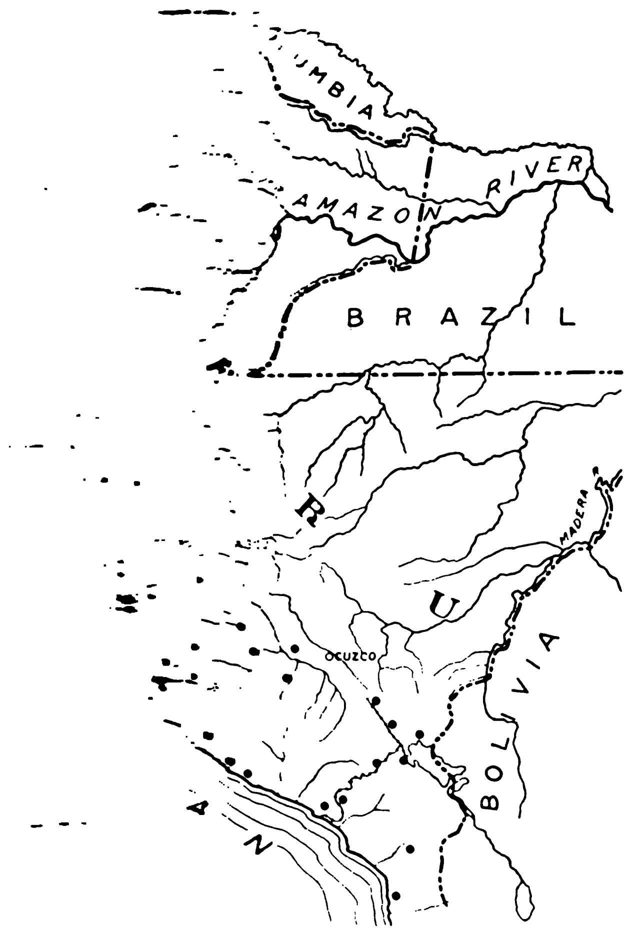
Though Ecuador contains several deposits of copper in the provinces of Loja and Azuay, their remoteness precludes present development. The Virginia mine was opened some years ago, but is not a producing property. The ores are highly argentiferous.

Peru

Peru may be the largest producer of South America, now that its chief mine, the Cerro del Pasco, is equipped with a modern plant, as the property is one of the largest copper deposits of the world. It is situated in the summit region of the Andes, 14,000 ft. above the sea, and east of the divide separating the waters of the Amazon from those tributary to the Pacific. It was formerly connected with the coast by an ancient Aztec paved pathway, but is now accessible by an extension of the Oroya

[1] Hans Ochmichen, *Zeit. für praktische Geologie*, 1902, vol. x, pp. 147–151.
[2] M. Vattier, *Mining Journal*, Sept. 8, 1906, p. 271.
[3] Tschermak, *Mineralogische und Petr. Mittheilungen*, 1901, vol. xx, pp. 390–398.

... difficult railway work in the ... the most famous silver mines of ... 1902 for their silver, the small ... into bluestone for use in the



... DISTRIBUTION OF COPPER DEPOSITS OF PERU

... In 1902 the mines were acquired by an ... output of 50,000,000 lb. of copper is ... works are completed.

The Santa Ines y Morococha produced 4,480,000 lb. copper in 1902.

The widespread distribution of the copper mines of Peru is shown on the accompanying map (Fig. 74). As yet, however, the argentiferous copper ores are the chief ores worked. Mining was done in 1903 in the department of Ica, and province of Yauli, and a Peruvian company operated a smelter at Huaraucaca.

The mineral belt of Peru is made up of Jurassic and Cretaceous rocks, cut by numerous intrusions of andesitic and dioritic rocks. Like the other Andean countries, Peru contains many veins of very rich complex copper-silver ores, of which the Recuay deposit may be described as typical.[1]

Recuay is the terminus of a railway line from Coquimbo, the first important seaport north of Callao. It lies about 200 miles north of Lima, in an interior valley between the coast range and the main snow-crested Andes. The veins occur in Jurassic limestones, shales, etc., cut by numerous intrusive sheets and dikes of basic lavas (melaphyres).

Two groups of veins occur: (1) east and west, (2) north and south. Copper ores are accessory in the east and west group, which comprises the richest veins of the district, but predominate in the north and south veins. The east and west or transverse veins contain complex sulphides of copper, with antimony, arsenic, and high values in silver, the purely copper ores being merely accessory. The Callaracoa vein has been worked for over $\frac{3}{5}$ mile in length, is 3 ft. wide, and has well-defined walls, with clay selvage. The Tarujos vein is thicker, less regular, and its filling grades into the country rock. Galena and rich silver sulphides, pyrite, etc., occur with the so-called "gray copper."

In the Moquegua district, in the province of that name, ferruginous quartz veins in granite are found in the Toquepala ravine, 40 miles southeast of the town. The ores are all oxidized, and carry 10 to 11 per cent copper and only traces of silver.

In the Ilo district, 12 miles north of the town of that name, cupriferous quartz veins in granite are worked, the ore averaging 20 per cent copper.

The greatest copper mine of Peru, and of all South America, is that of Cerro de Pasco.

Cerro de Pasco is a mining town of 7000 to 8000 people, situated on a low ridge in the middle of a hill-encircled basin of the central inter-Andean plateau, at an altitude of 14,000 ft. It has been famous as a

[1] Fuchs and De Launay, "Traité des gîtes minéraux et metallifères," 1893, vol. ii, p. 854.

FIG. 75. — TAJO DEL DESCUBRIDORA, LOOKING SOUTH, CERRO DE PASCO. (KLEPETKO)

silver mine since 1630, immense chambers being worked out in this great mass until the surface caved in, forming the enormous pits seen today, the largest, the Santa Rosa, being 300 ft. deep. All these pits served as exits for later workings. A large part of the district is now owned by an American syndicate that has extended the Lima-Oroya railway to the place, built a modern reduction plant, and developed the deposit.

The outcrops form great reefs (*crestones*). The rich ore is found in shoots or pipes, which are called *tajos* (workings), a name also applied to the pits. The rocks, according to Hodges, are Jurassic (?) limestones and older slates and quartzites, all with a steep easterly dip. These rocks are in contact on the west with an intrusive mass of biotite-andesite or dacite. According to Caswell's determinations, the dacite contains apatite both alone and in needles and clear crystals in the feldspar and biotite.

The orebody appears to be a great stockwork of altered andesite (sandstone and slate of Hodges) impregnated by vein-forming solutions decomposed by surface water, and carrying stringers, pockets, and masses of ore. The upper 200 to 300 ft. is brightly colored and highly altered by oxidizing waters.[1] The red oxidized ores (*pacos*) are underlain by very lean ores composed of pyrite with some copper pyrite, which rest upon the complex sulphide ores (*pavonados*) with tetrahedrite and various rich silver minerals. Below water level the primary ore consists of pyrite, tetrahedrite, blende, chalcopyrite, bornite, arsenopyrite, etc., in a clayey matrix inclosed in hard, slaty, and quartzose rocks. Gold and silver occur in these ores, probably in rich silver sulphides.

The orebody is supposedly located at the intersection of a north-south vein (Colquiroa) and a northeast vein (Pariajirca), both of which have been mined up to the limits of the stockwork.

According to Raimondi, the deposit is probably underlain by diorite,[2] which here, as in so many districts in Peru, has mineralized the deposit, the dacite being the later intrusion.

Copper deposits occur at Jauja and Huancayo. The ores consist of pyrite and chalcopyrite in a gangue of siderite, and manganiferous siderite. They occur in lodes cutting limestones, schists, and quartzites. According to Duena, the bornite and tetrahedrite of the veins are secondary.

[1] Fuchs and De Launay, "Traité des gîtes minéraux et metallifères," 1893, vol. ii, pp. 829–832.

[2] "Memoria Sobre el Cerro de Pasco," 1885.

FIG. 76. — TAJO SANTA ROSA, LOOKING SOUTH, CERRO DE PASCO. (KLEPETKO)

Bibliography

1852. Mines d'argent du Cerro de Pasco et mines d'or de Caravaya (Pérou), *Ann. des Mines*, 5^e, tome ii, p. 587.
1878. D'Achiardi. Minerali e rocce del Peru.
1878. Raimondi. Min. Pérou. Paris.
1878. Henry Sewell. On the mineral caves of Huallanca, Peru, *Ann. J. of Sc.*, no. 88, p. 317.
1879. Rath. Erinner. Pariser Weltaustell. Bonn.
1879. Anal. of the tetrahedrite from Huallanca, Peru, *Ann. J. of Sc.*, 1879, 17, 101, 401.
1879. Soetbeer. Edel Metal Production, Petermann's *Mittheilungen*.
1879. Les mines d'argent du Cerro de Pasco, *La Nature*, 10 May, 1879, p. 358.
1880. Percy. Metallurgy of gold and silver, p. 208.
1881. Du Chatenet. Ind. minér. dans le Cerro de Pasco, *Ann. des Mines*, 7^e, tome xix, p. 61.
1883. D'Achiardi. I metalli, tome i, p. 185.
1885. Raimondi. Memoria sobre el Cerro de Pasco, 1885.
1888. Hodges. Geology of the Cerro de Pasco, *Transactions* American Institute of Mining Engineers.
1906. Duena. Copper in Jauja and Huancayo, *Boletin cuerpo de Ing. de Minas de Peru*, no. 35, p. 120.

Venezuela

Venezuela not only has undeveloped deposits of great promise, but possesses one large property whose great veins were worked for some years, but are now idle because of the political conditions. The Narvaez or Bolivar tract, lying between the Yaracuay and Tocuyo rivers, contains numerous copper deposits, one of which, the Quebrada, was worked until 1894. The region is one of slates and limestones cut by igneous rocks. The ores occur in veins, with ore-shoots of lenticular shape. Sulphide ores, chiefly chalcopyrite, occur at shallow depths.[1] The Aroa or Quebrada mine, 67 miles west of Puerto Cabello, was shut down in 1894 on account of impossible political conditions after a prosperous career of fourteen years, and of over 271,770 tons of ore, valued at over $6,000,000.[2]

In 1894 there were fourteen producing copper mines in the country. At present there are no producing mines, but copper deposits are known in the Coro, Carabobo, Baraquisimetò, and Mérida departments.

[1] "Venezuela Handbook," Bureau of American Republics, Washington, 1904, p. 202.
[2] *L.c.*, p. 208.

XIV

COPPER DEPOSITS OF THE WEST INDIES AND CENTRAL AMERICA

CUBA

COPPER deposits occur at many places throughout the island of Cuba, usually associated with masses of serpentine, the oldest rock of the island. The ores consist of chalcopyrite, with pyrite or pyrrhotite, forming masses of irregular form and size found in zones of crushing in the serpentine. Such deposits occur from the province of Santiago to the extreme western end of the island; but their production has been limited, and the copper output of Cuba has come almost entirely from the Cobre mines near Santiago.

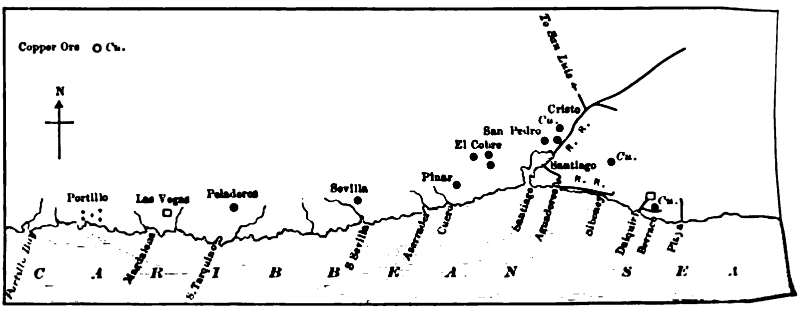
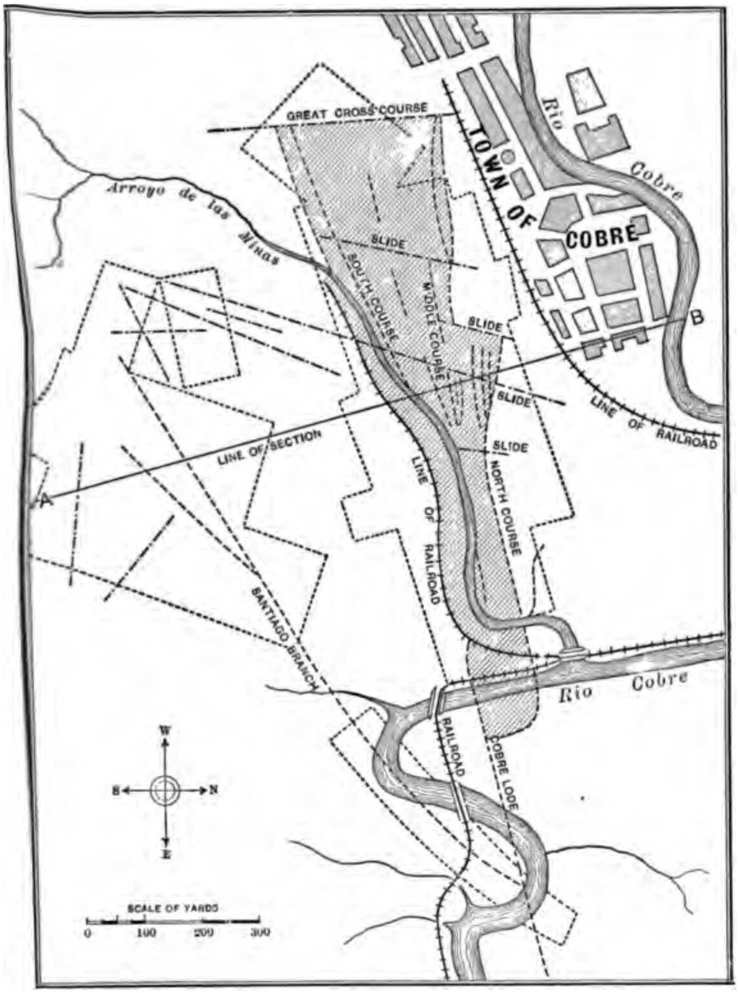


FIG. 77.—INDEX MAP SHOWING LOCATION OF COPPER DEPOSITS NEAR SANTIAGO, CUBA

The Cobre copper deposits were the most important ores of the We[illegible] Indies. The mines are about 8 miles west of Santiago, in the fo[illegible] of the Sierra Maestra, at an altitude of 2400 ft. A mine rai[illegible] from the town of Cobre to Santiago Bay. The ore occurs [illegible] veins, cutting through fragmental volcanic breccias and interb[illegible] flows, these rocks forming the base of the sedimentary series



Limits of Concessions

Lodes and Courses of Ore

Heaves and Cross Courses

The Breadth of Orey Ground in the Great Lode approximately marked

FIG. 73.—MAP OF EL COBRE VEINS, CUBA. (ANSTED)

strike east and west, and dip north, away from the Sierra Maestra. The veins occur in a mineralized zone that is several hundred feet wide and nearly a mile long, the rock between the veins being bleached and altered. The course of the veins is north-northeast and south-southwest. The map (Fig. 78) shows the Cobre lode and the parallel veins, together with the cross faults which shift the veins. The dip is nearly vertical. The main lode bifurcates to the southwest, and both branches become irregular and split up into a network of threads and stringers. The mineral zone has a lineal extent of about 5000 ft. and an extreme width of 600 ft., in which the main vein and its parallel rich branches occur, with intervening country rock. The primary ore consists of chalcopyrite often coated by covellite associated with pyrite in a gangue of quartz. According to Benjamin R. Lawrence,[1] the mines have produced between twenty and thirty million dollars' worth of ore. The ore came from three or four veins in a mineral zone 5000 feet long. These veins average 7 ft. in width, and are cut brecciated andesite. Many old stopes were 20 to 30 ft. wide. The oxide and glance ore went down 50 or 60 ft. below the outcrop, then chalcopyrite and pyrite ores with a silicious gangue and averaging 6 per cent copper came in. The ores carry only traces of the precious metals. The mines were unwatered in 1903; but the old workings 1300 ft. deep were caved and the mine was allowed to fill again.

Besides the Santiago deposits, copper is found, as already noted, in various localities scattered throughout the island. Very little recent information is available concerning these properties, and although the examination of Spencer[2] covered this particular feature of the geology, the workings were largely inaccessible, and one has to rely upon the old reports of Taylor and others. At Dos Palmas native copper and oxidized ore occur along a contact zone some 70 ft. wide, between shale and an intruded sheet of diabase.

According to Taylor, copper-bearing veins occur in the serpentine rocks near Gipara and near Holguin. The veins are regular, strike east-northeast, dip 65 deg. south, are parallel, and have polished, slickensided walls. Oxidized ore and native copper extend downward for 50 to 80 ft. from the surface. At the San Fernando property bornite and calcite occur. The San Augustine vein was opened by a shaft 40 ft. deep, in which showed a width of 3 ft. of 16.61 per cent ore. The Buena Isa-

[1] *Mining and Scientific Press*, Nov. 17, 1906, p. 602.
[2] Hays, Vaughn-Spencer, "Geology of Cuba."

lla vein is 3 ft. wide and developed by a 90-ft. shaft and drifts. At ıbana Vieja, 4½ miles from Gibara, there are eight veins running north 5 deg. east, and dipping 60 to 70 deg. south. The largest vein is 30 ft. ide, and the others are 4 to 6 ft. in width.[1]

In the province of Puerto Principe the old and formerly important

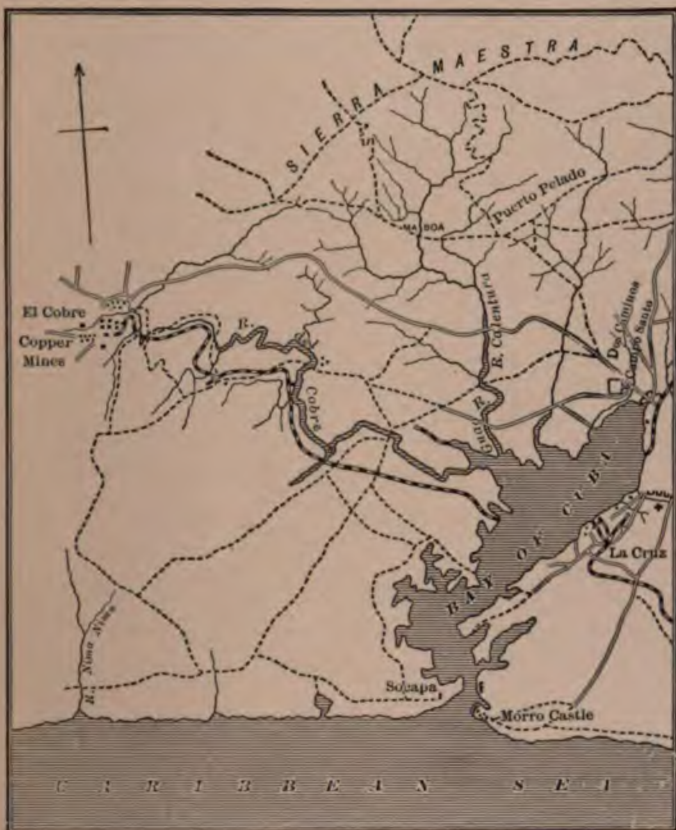


FIG. 79.—INDEX MAP SHOWING LOCATION OF EL COBRE MINES, CUBA

opper mines near Minas were situated on fissure veins of quartz carry- ıg chalcopyrite, and cutting through serpentine in an area of dioritic nd granitic rocks. These are several veins occurring in a zone that is alf a mile wide and three miles long.

[1] R. C. Taylor, *Proceedings* American Philosophical Society, 1846.

Santa Clara province contains five localities at which copper ores have been found, all of them to the northeast of Cienfuegos.

The deposits are all veins in diorite porphyries, or andesite with dikes of unaltered basalt and gabbro, of post-Cretaceous age. The chief deposits are as follows:

San Juan Maleja. — Gently rolling country underlain by serpentine and diorite. Gossan outcrop 100 ft. wide on contact of gabbro dike. Tunnels and oxidized ores, no primary ore being reached.

Santa Rosa. — Vein with northwest course, hanging wall of slickensided and brecciated serpentine, with footwall of sheared and altered feldspar porphyry. Vein 10 ft. wide, containing pyrite and chalcopyrite.

Finca San Juan. — Four mines in hilly country 1000 ft. above tide, on north side of Rio Arimao. These mines produced high-grade ore during 1856–1858, shipped to Wales. Work resumed 1882–1885, but property afterward abandoned.

San Fernando. — Barytic veins in diorite porphyry. Ore, pyrite, chalcopyrite, and blende. Nearly vertical lodes, one 35 ft. wide, composed of pyrite and chalcopyrite, with a little blende. Picked samples contained copper, 8 36; iron, 57.34; gold, 0.15 oz.; silver, 4.7 oz.; Sta. Elena and Isabella, veins in diorite porphyry. San Jose, pyritic and quartz veins in porphyry.

Matanzas. — The copper ores are found at El Recreo in fissure veins in serpentine, the largest traced for 1400 ft. Course north 10 deg. east, dip 80 deg. west. Oxidized ore extends downward but 20 ft. The bornite varies from a mere streak to 20 in. wide, and to the north splits into diverging stringers. Old copper mines exist near Minas, 8 miles east of Havana, and a few miles from Guanabacoa. The ores consist of chalcopyrite mixed with pyrrhotite, and occur as lenses in a serpentinized peridotite. This rock is much fissured and the largest orebody faulted. The deposits are of the Monte Catini type and of sporadic occurrence.

The orebodies of the Minas deposit are well defined and lenticular in shape, 20 ft. to 200 ft. long, with an extreme thickness of 20 ft., and have a northeast pitch. The ore is solid, has a fibrous grain, and passes gradually into lean ore and this to country rock. Three deposits are known, one opened to a depth of 280 ft. vertical. The best ore carries 10 per cent copper, but the orebodies, as a whole, are lower grade. The impregnated rock carries up to 1 per cent copper, and some of the pyrrhotite is almost devoid of that metal. The locality shows many prominent limonite gossan outcrops, but these are mere surface cappings. No secondary sulphides occur, and oxidized ores are practically absent. As fissure lines appear to govern the distribution of the orebodies, prospecting should follow such lines.[1]

Pinar del Rio. — Copper deposits also exist near Arroyo de Mantua, in the westernmost province of Cuba. The ores consist of chalcopyrite and pyrrhotite with a schistose structure, accompanied by pyrite and chalcocite. The ore occurs in lenticular shoots in metamorphic schists divided from igneous rocks. Extensive limonite gossan bodies occur above the ore. The deposits are said to be extensive and to be valuable as pyrite producers as well as from the copper contained in them.

Jamaica

Jamaica contains a number of copper veins whose average width is from 3 to 4 ft., and which cut the igneous rocks in the center of the island in a northeast and southwest direction, parallel to the great valleys of the island. A few of these veins were explored about 1854, the main vein having a course of north 35 deg. east, and showing an average width of 3 ft. The ore shoot showed a streak from ¼ in. to 8 in. wide, consisting of bornite. A shipment of ore containing 24½ per cent copper was made to the Revere Copper Company of Boston.[2]

Santo Domingo and Hayti

This island possesses deposits of copper, both in Santo Domingo and in Hayti, but, though worked by the Spaniards in the eighteenth century, there are at present no productive mines and but few deposits that are being developed. The island is a mass of mountains separated by a few large valleys. The core of the island is composed of hornblendic granite and syenite thrust up through Tertiary limestones and shales. The copper deposits occur in connection with great intrusive bodies of basic igneous rocks. The ores contain bornite and chalcopyrite, and a little gold and silver. The ores occur in fissure veins in diorite porphyry, and in altered limestones near the igneous contacts. The deposits near the Jaina and Nigua rivers in the province of San Christobal on the south side of the island are being

[1] Weed, "Copper Mines near Havana, Cuba," *Engineering and Mining Journal*, Jan. 26, 1905, p. 176.

[2] Dr. Isaiah Deck, "Mineral Lands of Jamaica," *Mining Magazine*, vol. iii, 1854, p. 200.

worked, the San Francisco property being lately, according to reports, equipped with a small smelter. There are also very promising veins of quartz carrying chalcopyrite at Barrero, about 23 miles from the city of Santo Domingo, beyond the terminus of the La Fé Railroad.[1]

FIG. 80.—MAP SHOWING LOCATION OF BARRERO COPPER DEPOSITS, SANTO DOMINGO, WEST INDIES

In the western part of the island, in Hayti, there are exten deposits of copper ore associated with a line of igneous (and

[1] F. Lynwood Garrison, *Cassier's Mag*

rocks intruded in Tertiary limestones. The deposits center about Terre Neuve, some 10 miles from the seaport of Gonaives. Extensive masses of limonite cap oxidized and sulphide ores — mainly chalcopyrite, which are found as large nests and pockets and disseminated through the garnet rock formed by contact metamorphism. The line of deposits is traceable for some seven miles. The igneous rock is an andesite with diorite intrusions. The deposits are low rade.[1]

Copper deposits also exist in the region south of Le Cap in 19° 35′ orth latitude and 72° 5′ west longitude, at Grande Riviere, on the west ide of the river of that name, 6 to 10 miles south of the sea. The eposits show glance and carbonate ores of copper in vein in a basic gneous rock (melaphyre). At Limonade the copper ores carry considerable platinum and osmiridium, thus resembling the ore of the udbury (Canada) deposits and the covellite ore of the Rambler mine, Vyoming.

GUATEMALA

In Chuquimala, the eastern department of the republic, there are umerous deposits of copper, said to run from 5 to 20 per cent. The Northern Railway will, when completed, open up this section. At the resent time (1906) none of the deposits are worked.[2]

"In the mountains of Motoziatla of the Pacific coast range there are leposits of copper carbonates. Auriferous high-grade copper ores are ound on the south slope of the Cuchumatanes Range, in the department of Huehuetenango." The ore is "high-grade clean carbonate, lying in a contact formation between limestone and syenite." Small veins of pure malachite occur near Ravinal and Cabulca.[3]

HONDURAS

A group of eight well-defined veins of "good width and long extent" is reported in the department of Yoro, in a forest region 40 miles from the navigable Ulue river, and 20 miles from a coal-field.[4]

[1] L. Gentil [illegible]: Petermann's *Mittheilungen*, vol. xlvii, 1901, p. 130.

[2] *Boletin* [illegible], quoted in the *Mining Journal* (London), May 12, 1906, p. 612.

[3] *Bulletin* [illegible] Bureau of [illegible]merican Republics, January, 1898, pp. 50, [illegible]

[illegible] May 19, 1905.

SALVADOR

The mineral veins of Salvador are found principally in the mountain chain which extends into Honduras, Nicaragua. They run southwest, parallel with the range; and copper ores are mostly in the eastern part of the republic, i.e. in Santa Ana and Chalatenanga.[1]

[1] *Bulletin* No. 58, Salvador, Bureau of American Republics, 1894, p. 58.

XV

COPPER DEPOSITS OF CANADA AND NEWFOUNDLAND

THE great copper mines of Canada are found in British Columbia, though the eastern provinces contain many small and generally unworkable deposits, with two producing mines in Quebec. Copper is, however, an important by-product of the nickel mines of the Sudbury district, Ontario, of the silver ores of Nelson, B.C., and of the gold mines of Rossland. The great copper camp of the country is the Boundary district in British Columbia; but the Pacific coast contains many deposits, those of Vancouver Island and Texada Island producing an increasing amount each year.

The copper production of Canada for 1905 was 47,597,502 lb., placing it fourth in the list of copper-producing countries. Of this total British Columbia produces 80 per cent. Of this latter amount the Boundary district yields 60 per cent, Rossland's gold-copper mines furnish 20 per cent, and the coast district 16 per cent, with 3 per cent from the Yale, Nelson, and Kamloops district. The recent increase is all from the Boundary.

In Quebec the copper production is entirely from pyrite ores, and that of Ontario from the nickel copper deposits of Sudbury.[1]

NOVA SCOTIA AND NEW BRUNSWICK

The deposits of the eastern provinces have been recently studied and reviewed by R. W. Ells,[2] who finds those of Nova Scotia and New Brunswick to belong to four types, viz.: (1) pyritic ores forming lenses in crystalline rocks of pre-Cambrian age and felsitic character; (2) contact deposits of bornite and chalcopyrite between Silurian and Devonian limestones and dioritic intrusions; (3) gray copper associated with plant remains and lignite fragments in sandstone and conglomerate of upper

1 ...ing *Journal*, vol. lxxxi, 1906, p. 524.
...ces of Nova Scotia, New Brunswick, and Quebec," *Bulletin*
...

Carboniferous or Permian age; (4) native copper in Triassic basalts of the Bay of Fundy.

The deposits of the first class, found at Coxheath, near Sydney, Cape Breton Island, have been extensively developed, one shaft reaching a depth of 420 ft. The mine is not yet productive.

The basaltic lavas and ash beds of the Bay of Fundy contain considerable native copper, the deposits being of the fourth class mentioned above. The Colonial Copper Company has been developing the deposits exposed in the high cliffs on the shores of this bay ever since 1900, and will definitely determine whether the deposits can be placed upon a paying basis or not.

In New Brunswick the only deposit that has been extensively developed is that of the Dorchester mine, where gray copper and, rarely, other ores occur in red sandstones of Carboniferous (millstone grit) age. The deposit has not proved payable.

QUEBEC

The cupriferous pyrite deposits of Quebec are, according to Ells, of a different type from those just mentioned. The deposits lie due north of the Vermont copper district, in the Eastern Townships of the province, and occur in three distinct belts, about 25 miles apart and about 2 miles wide, where they are cut by the St. Francis river. The work of Dresser[1] shows the talcose, micaceous, and chloritic schists of the region to be disguised volcanics of early geologic age and variable composition, but largely of diabasic character.

The Ascot or Eastern belt, in which the Eustis and Capel mines, near Capelton, occur, is the only producing district. The so-called sandstones of this belt are a complex of volcanic rocks, the Suffield rock being a quartz-porphyry. The ore occurs in distinct lenses, which apparently follow the cleavage, and are like bedded veins, but sometimes overlap, the axes crossing the foliation of the rocks. These lenses vary from a few feet to 30 ft. in thickness, and up to 100 ft. in length. They are sometimes cut by trap (camptonite and olivine diabase) dikes.

The Capelton (Eustis) mines are only a few miles north of the Vermont line. The ores are low-grade, carrying but 2 to 3 per cent copper and about 4 oz. silver per ton, but are valuable for sulphuric acid manufacture, the residual cinder being sme ted for copper.

[1] *Engineering and Mining Journal*, vol. … nal …
Institute, vol. v, 1902, p. 81; *Economic Geol* … 4

The Western belt, about 60 miles east of Montreal, embraces the now idle mines of Acton, Upton, Roxton, Wickham, and St. Flavien. The orebodies are in limestones, with associated black, graphitic shales intruded by igneous rocks, the copper deposits being in or near the latter rocks.

Ontario

The copper produced in Ontario comes from the nickel mines of Sudbury, but copper deposits occur in other parts of the province.

The Parry Sound copper district of Canada lies on the eastern shore of Georgian Bay and along Parry Sound.[1] The district is a rough and glaciated region, largely of bare rock. The rocks consist of disturbed and contorted gneisses and schists, garnet schists prevailing along Parry Sound. Numerous small quartz veinlets and several large pegmatite dikes occur. The ores are found in a cupriferous belt 1000 to 1400 ft. wide, the ores occurring in mineral veins or beds, forming extended and more or less parallel lenses running with the mineral channel, and either vertical or dipping steeply. This mineralized belt is probably a zone of fracture marking a fault. The beds vary from a few feet to 30 or 40 ft. thick, and at several points aggregate 300 to 400 ft. They are usually capped by limonite gossan, an infrequent feature in a glaciated region. The ore is mostly iron pyrite, with chalcopyrite, and at some points with bornite and glance. Three dollars to $10 in gold per ton is the usual run. Blende is common, and occurs up to as much as 15 per cent of the mass. At La Fex mine 2½ per cent of nickel occurs.[2]

The Copper Bay, Bruce, and Wellington, well-known, intermittently producing mines, are in a district some 35 miles east of Sault Ste. Marie, in the Algoma district, on the north shore of Lake Huron. The ores consist of bornite and chalcopyrite, found in veins of white quartz cutting through Huronian rocks. The veins are developed to a depth of 400 ft., and for 8000 ft. in length. The mines are well equipped; but thus far no profitable mining has been possible. The Massey Station, Hermina, and Superior mines were worked in 1906. At Mamaisne Point, 60 miles north of the Sault, the copper-bearing Keweenawan rocks of Michigan occur; but extensive development work at various periods has thus far failed to yield adequate returns.

Sudbury District. — The copper produced in the province of

[1] *Report* of the Bureau of Mines, Ontario, vol. xiv, part i, p. 60; vol. xv, part i, p. 67.

[2] Thomas Kirby, *Engineering and Mining Journal*, vol. lxxiv, pp. 186, 187.

Ontario comes almost entirely from the nickel mines of Sudbury. This, the most important nickel district of the world, lies north of Lake Superior on the line of the Canadian Pacific Railway. The district is part of a general uneven, undulating, rocky plain with gentle south slope. In detail it consists of a succession of parallel, disconnected, rounded rocky ridges, with northeast to southwest course, separated by swamps, lakes, and stream ways. The elevation varies from 800 to 1000 ft. above tide.

According to Coleman,[1] the igneous rock with which the nickel-copper ores are associated forms a basin, being an immense laccolitic sheet of synclinal form, inclosing tuffs and ordinary sediments within the basin. The outcrop varies from 1 to 4 miles in width. The rock is basic (norite) on its outer border, shading inward to a pale gray or pink micropegmatite, which in turn passes into granite. Barlow[2] does not admit the passage of the norite into the granite, but believes they are distinct intrusions of nearly the same age. The sedimentary rocks of the region consist mainly of quartzite, arkose, and graywacke, and include bedded volcanic tuffs and conglomerates. These rocks become gneissoid as the nickel range is approached, becoming very massive and dense hornblendic and chloritic rocks near the borders of the norite, and containing porphyroids and porphyrites. All the orebodies occur on the outer margin of the mass of norite (commonly altered to diorite), whose more or less continuous outcrop incloses an oval area that is 35 miles long and 8 miles wide. The ore deposits only occur on the borders of this eruptive rock, and are of two types: (1) The marginal deposits, as, for example, those found along the southeast margin of the main range. These deposits are of irregular stocklike shapes, often occur crowded in baylike indentations of the adjoining rock, and are distinguished by a fairly sharp footwall, the ore fading gradually into the rock. (2) Cylindrical or chimney-shaped deposits, strung out on thin arms or offshoots of the main mass of igneous rock.

The copper occurs as chalcopyrite associated with pyrrhotite, the relative proportion being in the production in 1902 of 4066 tons of copper and 5945 of nickel, the ore averaging 1.74 per cent copper and 2.54 per cent nickel. The chief production is from the Creighton mine, whose immense orebody as defined by workings and diamond drillings is a

[1] *Report on the Sudbury District.* Ontario Bureau of Mines, Ottawa, 1905, pt. iii.

[2] *Report on the Geology of the Sudbury, Ontario, Nickel Deposits.* Canadian Geological Survey, 1906.

great lenticular chimney lying against a granite footwall, and dipping to the north at about 58 deg. It is estimated that 3,500,000 tons of 5.5 per cent nickel ore have been proved by the development at this mine.

The genesis of these remarkable deposits has been very generally accepted as due to magmatic differentiation. The work of Dickson predicated a brecciation of the rocks, with subsequent ore deposition,

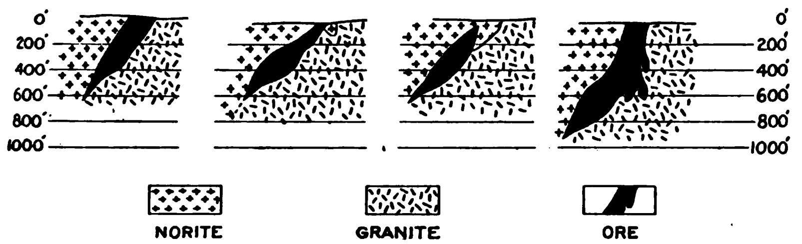


FIG. 81.—CREIGHTON OREBODY, SUDBURY DISTRICT, CANADA

by vein-forming waters. Both Coleman, of the Ontario Mining Bureau, and Barlow,[1] in the official report of the Canadian Geological Survey, regard the deposits as due primarily and principally to magmatic differentiation, with minor reconcentration by magmatic waters, especially where brecciation due to intrusion formed channels for such circulations. The following analyses of the rocks of the great orebodies show the ratio of copper to nickel to be the same in the rock as in the ore.[2]

	Creighton Norite	No. 2. Mine Norite	Creighton Diabase Dike
Copper	.10	.15	.10
Nickel	.30	.30	.35
Silica	47.70	47.82	49.60
Sulphur	.44	.45	.45
Iron	9.65	9.45	11.80
Alumina	15.23	16.57	15.40
Lime	8.72	7.32	7.23
Magnesia	6.55	6.62	4.28

[1] "On the Origin and Relations of the Nickel and Copper Deposits of Sudbury, Canada." *Economic Geology*, vol. i, p. 454.

[2] David H. Browne, "Notes on the Origin of Sudbury Ores." *Economic Geology*, vol. i, p. 467.

CREIGHTON ORE

Copper	1.30	Nickel	5.5
Iron	44.60	Sulphur	29.9
Silica	8.66	Alumina	7.4
Magnesia	2.32		

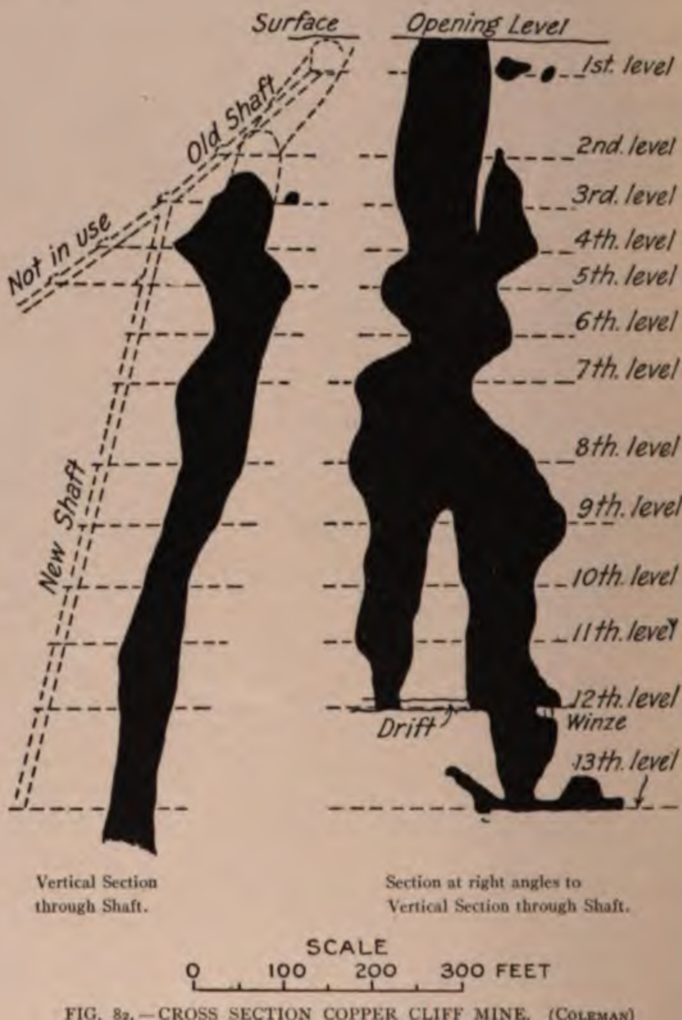


FIG. 82.—CROSS SECTION COPPER CLIFF MINE. (COLEMAN)

The ores are very similar at all the mines, though varying slight in the percentage of copper. The Canadian Copper Company wo the Creighton and Copper Cliff mines. The Victoria mines (Mond Nickel Company) were in 1905 the only other producers. Extensive deposits along the northern range are as yet unworked.

British Columbia

Rossland District. — For many years past the gold-copper deposits of Rossland have yielded large amounts of copper as a by-product. The district occurs on the outskirts of the town of Rossland, on the flanks of Red Mountain, a few miles north of the international boundary line, and almost due north of Spokane, Washington. The mines have yielded from 1894 to 1905 $33,839,342, the average value being about

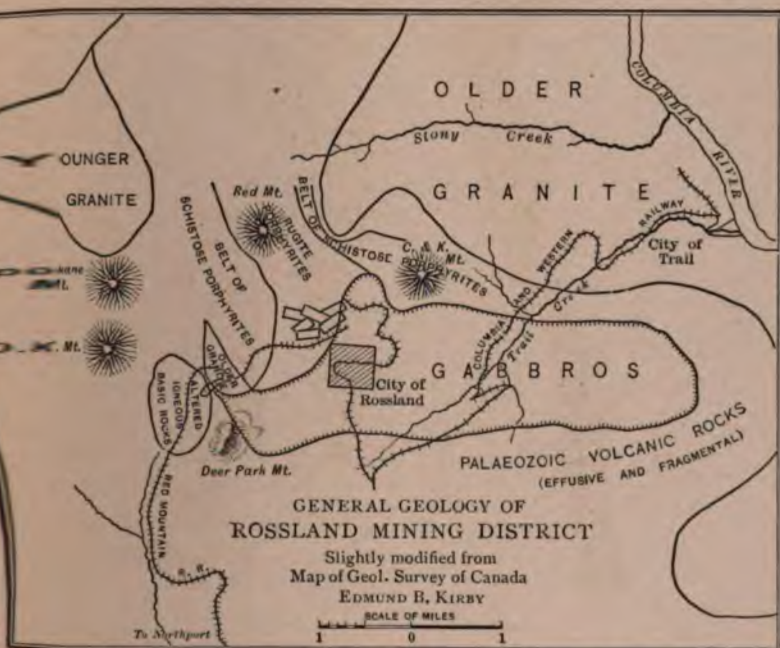


FIG. 83. — MAP OF ROSSLAND DISTRICT, BRITISH COLUMBIA

$15.25 per ton. The district contains 19 producing mines, but the output comes mainly from four mines, the Le Roi alone yielding considerably over one-half.

The typical ore consists of more or less altered rock with reticulating veinlets, irregular masses and impregnations of pyrrhotite, varying amounts of chalcopyrite, and a little quartz, the sulphides forming 50 to 75 per cent of the mass. The copper pyrite is often of later formation than the magnetic pyrite. Arsenopyrite and iron pyrite sometimes occur. The typical ore varies, on the one hand, to solid sulphides forming large masses and ore shoots, and, on the other, to payable though but slightly mineralized rock. The ore minerals include, besides those mentioned, native gold, bismuthinite, molybdenite, and rarely galena and blende.

The rock forming the gangue is peculiarly altered, fresh biotite having formed in abundance together with silica. Chlorite and hornblende are abundant in places, and muscovite, tourmaline garnet, and wollastonite also occur. Zeolites are present where hydrothermal alteration is marked, and epidote with molybdenite and bismuthinite occur at the Jumbo mine.

The values of the ore are mainly gold, and were best near the surface. The following average analyses are typical of the ore mined by the largest producers. The gold and silver are given in ounces per ton.

Gold	Silver	Copper	Iron	Silica	Sulphur	Lime	Alumina
4.41	0.5	1.15	19.8	43.	7.25	8.7	15.
.5	0.3	0.9	22.	37.	10.8	4.2	14.9
.4	0.54	0.7	15.5	42.	6.8	17.6	
1.18	2.318	3.62					

The ore deposits are either (1) fissure veins with or without replacement; (2) lodes or zones of shearing, in which the ore minerals form a network of veinlets in fractures and replace wholly or partly the intervening rock; (3) irregular impregnations of country rock.

The most important orebodies occur in lodes, grouped as shown in the accompanying map of the district, and dip north, usually at 60 to 70 deg. The walls are ill-defined.

The veins sometimes cross basic dikes, but more often are faulted by them; but much of this displacement is due to faults in ore following along dikes.

The outcrop is a brown limonite gossan, varying to an iron-stained rotted rock; but it is not deep, sulphides showing a few feet down.

The pay ore occurs in shoots which vary greatly in size and shape. Lenticular bodies are most frequent, but many shoots enlarge and terminate abruptly against a dike or a fault. The shoots vary from a foot to 130 ft. in width and 50 ft. to 500 ft. in length, the downward extension being greatest. One shoot worked for 500 ft. vertically has averaged 150 ft. long and 56 ft. thick. The shoot shows a marked pitch, but in various directions. The best ore occurs in bands in the shoots, usually parallel to the vein, but varying in position. A persistent seam of calcite in the main Le Roi-Center Star vein forms a useful indicator. Oftentimes faults and dikes make it difficult to follow the vein from shoot to shoot. Though no general rule governs the location of ore shoots, several conditions are favorable; viz. (*a*) the under side of a dike, or of a fault with an impervious selvage; (*b*) cross fractures in the solid wall rock are frequent near ore shoots; (*c*) contacts are favorable, especially at the Le Roi, between augite porphyrite greenstone and either monzonite or granodiorite porphyry.

The proved productive ground lies near or between exposures of the alkali-syenite; and in this area the stratified rocks hold disseminated ore too low-grade to pay. The ore is not as yet successfully milled.

The lowest grade of ore now mined (June, 1906) carries $6.00 to $7.00 gold and 0.6 per cent copper. The output is 1000 tons per day. About 2,000,000 tons, carrying $30,000,000, has been mined from 100 acres in 12 years. The twelfth level at 1530 feet down on the Center Star vein carries $12.00 ore, and there is no evidence to indicate a lessening of value in depth.[1]

The Le Roi vein is 20 to 40 ft. wide, and dips at 70 deg. to the northwest. The Josie vein is parallel to this, while the other veins are branches of the Le Roi.

The ore shoots are commonly of irregular form and large size, that of the War Eagle being 300 to 450 ft. along the vein, and pitches at 90 deg. to the vein. The entire width of sheeted rock is sometimes replaced; at other times only a narrow zone is mineralized, and the ore jumps across from one set of plating fissures to another, thus shifting the pay streak from the hanging to the footwall. In the Le Roi vein the footwall fissure is the more regular and distinct, and is marked by nests of interlacing calcite seams. In the War Eagle the reverse obtains. Mineralization extends irregularly and fades off gradually in the walls. Dikes and faults displace the veins and exercise an important influence on ore deposition, though barren themselves. The fissuring being deep, thermal waters circulating in them decomposed and replaced the rock either as a deposit along one plane or fissure, or replacing and filling the space between two planes, or even replacing the whole zone. The replacement of the rock minerals, particularly augite and diallage, was by pyrrhotite and chalcopyrite,

[1] R. W. Brock, Canadian Geological Survey, 1906, No. 939.

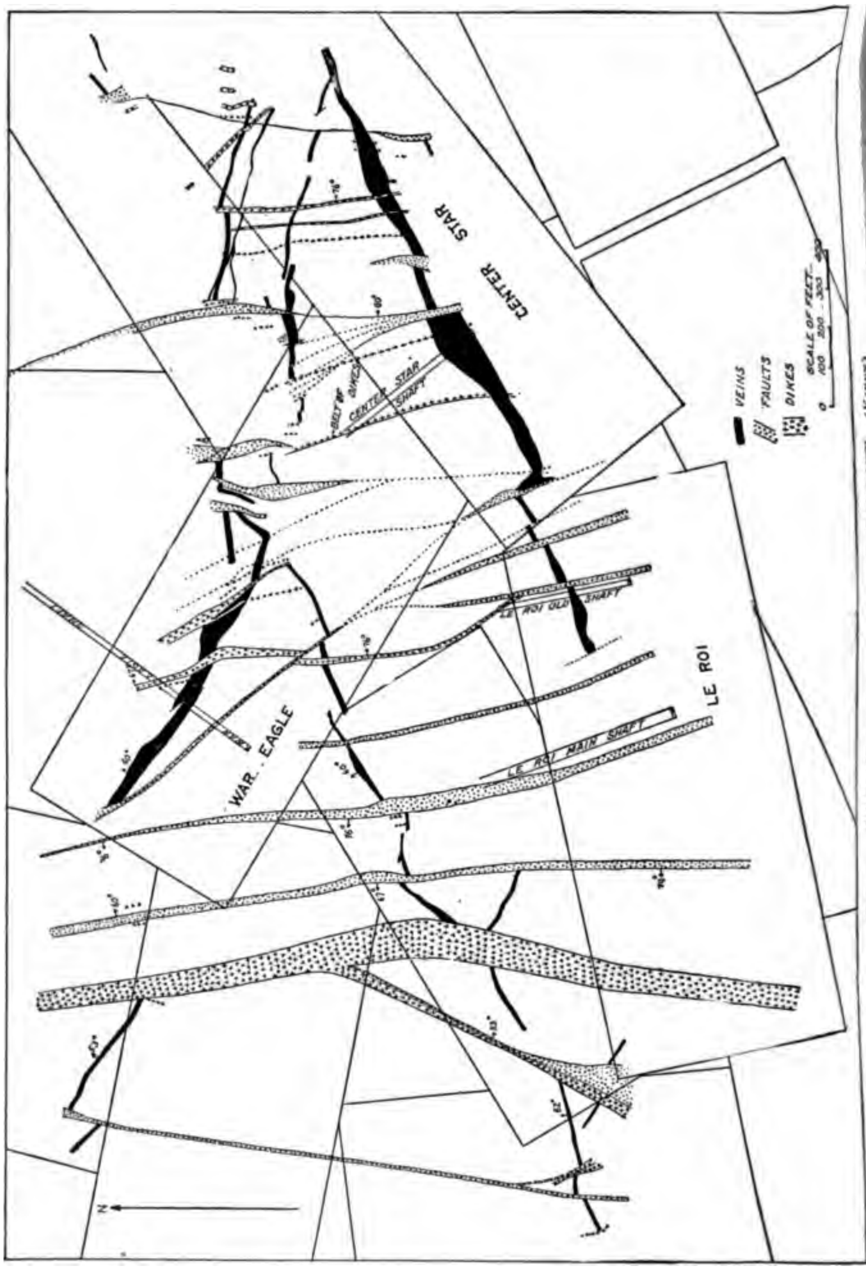


FIG. 84.—VEIN STRUCTURE, ROSSLAND DISTRICT. (Kirby)

and where intense alteration occurred solid ore was formed. The rocks being sheared and fractured but not brecciated, the ore replaces the country rock in veinlike sheets, and where partial replacement occurs the rock appears impregnated, and the ore contents gradually fade out from the solid ore of the fissure into the rock forming the walls. Where the ore ends abruptly it is caused by a slip limiting the circulation of the waters. The gangue of these veins is unique. The principal mineral is biotite. Associated with this there is a little quartz, calcite, muscovite, amphibole, chloritoid minerals, and garnet. A microscopic examination of the ores shows them to be formed as replacement deposits of the country rock, forming ore minerals on both sides of a narrow fissure (see Fig. 8). The hornblende changes to biotite, which invades the feldspar. Simultaneously with this, the feldspar is replaced along cracks by pyrrhotite and chalcopyrite, forming a characteristic network, and finally replacing all the rock. Extreme biotitization results in the fine-grained silicious rock which is composed of brown mica and quartz.

The production for 1903 was 155,765 tons, carrying 1.526 per cent copper, 0.709 oz. of silver per ton, and $7.46 gold per ton.[1]

Boundary District. — This, the most important copper-producing district of Canada, is situated near the international boundary line, west of Rossland, and between the north fork of Kettle river and Boundary creek. The mountains are not rugged, but outcrops are rare, as glacial débris covers the rocks. The district consists of sedimentary rocks, intruded and altered by various granites, greenstones, and porphyries. Volcanic tuffs occur, and basic dikes cut all the other rocks. The sedimentary rocks are the oldest, including argillites and limestones. Greenstone, the most widely distributed rock, is next in age; it is, partly at least, an augite-porphyry. This is cut by dikes of gray granite porphyry, offshoots from a mass of gray hornblende biotite-granite, exposed near Greenwood. It is regarded as Jurassic. Beds of volcanic rocks, remnants of a sheet of volcanic lavas, tuffs, etc., occur at several points. Dikes of reddish or yellowish syenite-porphyry, with segregations of biotite and feldspar, are common about the mines.

The orebodies are commonly regarded as contact metamorphic deposits. They are of enormous size, the Mother Lode deposit, according

[1] W. Lindgren, "Genesis of Ore Deposits," p. 564; E. B. Kirby, "Ore Deposits of Rossland, B.C.," *Journal* Canadian Mining Institute, vol. vii; R. W. Brock, Preliminary Report on the Rossland, B.C., Mining District. No. 939, Geological Survey of 1906.

FIG. 85.—OLD IRONSIDES SHAFT, GRANBY MINE, PHOENIX, B.C.

to Brock,[1] being 1180 ft. long and 140 ft. wide, and of unknown depth, but proved for 500 ft.

The Knobhill Ironsides outcrop is 400 ft. wide, and on the second level 800 ft. wide. The depósits are regarded by Brock as composite veins formed by metasomatic replacement of rock by mineralizing magmatic solutions traversing shear zones.

The ore is (*a*) pyritic, (*b*) magnetitic. In the pyritic ores pyrrhotite is the predominant metallic mineral, with accessory chalcopyrite and some pyrite. In the other variety pyrrhotite is replaced by magnetite. Other sulphides appear as accessory minerals, viz. arsenopyrite, galena, sphalerite, and molybdenite, and more rarely tetrahedrite, bismuthinite, and specularite. The veinstone consists of calcite, garnet, epidote, quartz, and jasper, and at the Mother Lode the chief mineral is actinolite. Tremolite occurs at one mine.

The ore deposits occur in all rocks, but mainly in greenstone and the altered limestone, but also in serpentine, argillite, and gray granite. Flat syenite-porphyry dikes cut but do not disturb the orebodies. The deposits are regarded by many observers as due to deposition from magmatic vein waters.

The ore of the Brooklyn mine, regarded as typical, contains: silica, 39 per cent; lime, 17 per cent; ferrous oxide, 14 per cent. Ledoux,[2] from smelter returns, gives the limiting values as 25 to 35 lb. of copper per ton (2000 lb.); $1.50 to $2.50 gold per ton; and 25c. to 40c. per ton silver. The same writer gives the mining costs at $1.66 and the smelting costs at $2 per ton, a total of $3.66.

The Mother Lode orebody is from 80 to 160 ft. wide, traceable for 1100 ft. north of the shaft, and then is, presumably, faulted, as no ore is found on the northward continuation in the prospect shafts put down. The southward continuation of the ore channel is seen in exposures some 700 ft. south of the shaft, but the workable ore does not extend more than a few yards south of the shaft. The main shaft is now 350 ft. deep, with levels at 200 and 300 ft. The 400-ft. level is started and is accessible by a winze. On the 200-ft. level the orebody is from 100 to 125 ft. wide, and has been developed for 900 ft. north of the shaft. The 300-ft. level is about the same.

The output for 1905 was 188,000 tons, and the total output from 1901 to 1905 amounts to 754,000 tons. The ore becomes less basic with depth,

[1] R. W. Brock, Preliminary Report on the Boundary Creek District, British Columbia. *Report* Canadian Geological Survey, pp. 90–136.

[2] A. R. Ledoux, *Journal* Canadian Mining Institute, vol. iv, 1901, pp. 184–189.

i.e. it has less magnetite and specular iron. The present output is about 600 tons per day.

The Emma mine is a typical magnetite and chalcopyrite contact deposit in garnetized limestone. At 150 ft. below the top the vein is 18 to 20 ft. wide and has been drifted on for 70 ft. The total output to the end of 1905 amounted to 80,000 tons.

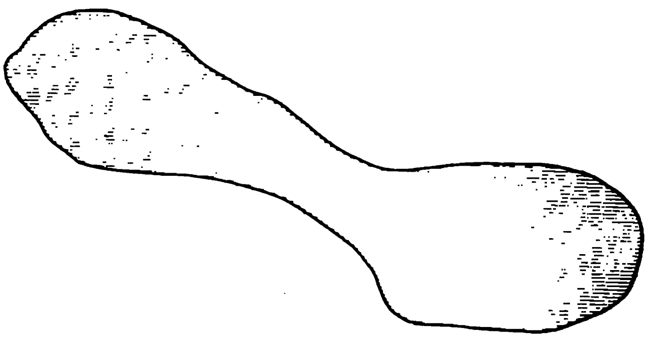


FIG. 86.—PLAN OF OREBODY, MOTHER LODE, GREENWOOD, BOUNDARY DISTRICT, B.C.

Similkameen District.—The Copper Mountain mines are south of Princeton, on the Tulameen river. The Swede group is on Bear creek, a north tributary of the river a couple of miles above Tulameen city. There is an ore zone 1000 ft. wide, in which some 500 ft. is workable ore, consisting of decomposed sericitized granite carrying chalcopyrite. An average sample across 300 ft. of the zone is said to assay 5 per cent copper. The property is gossan-covered, and the ore zone traceable for a mile or more.

Vancouver Island

Copper ores, associated with deposits of magnetic iron ore, occur in a belt which extends along the entire western side of Vancouver Island, parallel to the general coast line. This belt is cut across by the numerous deep transverse inlets of the island, affording deep-water transportation to many of the deposits.

The orebodies consist of magnetite, with lenses and segregations of copper pyrite near and along the contact and with local bornite enrichments and a garnet gangue. The deposits [illegible] the general line of contact between the granitic igneous

FIG. 87.—BRITISH COLUMBIA COPPER COMPANY'S SMELTER, GREENWOOD

core of the island and the coastal belt of dark green, highly altered shales and limestones, of the Vancouver series (locally termed diorites). The latter rocks are intensely altered by contact metamorphism due to igneous intrusions, and are disturbed by later faulting.

The orebodies are replacements of marble and of greenstones. These replacements occur at the actual contact with dikes and bosses of igneous rock and also along fracture and joints, especially at their intersections. The copper ore occurs in irregular shoots, whose distribution cannot be determined satisfactorily from surface examination.[1]

Sydney Inlet contains deposits of the magnetite and copper type with bornite and copper glance as well as chalcopyrite. In the workings chalcopyrite increases and magnetite decreases with depth; the bornite is found in sheeting planes. The gangue is quartz and actinolite.

At the Monitor mine, on the Alberni canal, altered shales and limestones are cut by a hornblende granite dike, 100 ft. thick, the ore occurring in brecciated zones at or near the contact. The ore is a mixture of chalcopyrite, pyrrhotite, and coarse magnetite, filling interstices, and holding unreplaced rock fragments.[2]

"Blanket veins" of secondary sulphides formed from sulphate solutions derived from weathering of some blind sulphide orebody usually near by, reduced by organic matter, are of common occurrence in the mineral belt. Such deposits are delusively attractive until opened up. Smelter returns show that the average ores carry 20c. to $1.00 a ton in gold, 2½ up to 10 oz. silver, and 2 to 40 per cent copper.

The Wahment mine near the Monitor is similar in character, as are also numerous prospects on the southeast shore of the Alberni canal.

The Yreka mine at the extreme north end of the island was worked for some time, but proved low-grade and patchy and is now idle.

At Goldstream, the rocks are semicrystallized schists, slightly graphitic. This belt runs north 60 deg. west, and is adjoined by the igneous belt, showing marble, granite, and other igneous rocks to the northeast, and in which the deposits of magnetite and copper pyrites occur. The Alberni belt is hornblende-schist. The Clayoquot Sound belt is northeast of the Alberni canal.

The deposits of Vancouver and Texada islands all appear to be contact deposits in limestone next to diorite or gabbro intrusions. They consist of magnetite with associated pyrrhotite, bornite, and copper pyrite.[3]

[1] C. F. Lee, *Report* of Minister of Mines, British Columbia, for 1901, p. 1099.

[2] T. R. Marshall, *l.c.*, p. 1905. [3] *Report* of the Provincial Mineralogist, 1897.

The orebodies are traceable for 500 to 700 ft., forming pockets running in a range or line. The orebodies occur either in the igneous rocks, at their contact, or in the limestones.

The mineral association is magnetite, chalcopyrite, hornblende, and garnet. In some places the magnetite predominates almost to the exclusion of the chalcopyrite.[1]

The *Tyee-Lenora* copper deposit is the most important one yet found on Vancouver Island. According to Clermont Livingston, who developed the property from a mere prospect to a mine that has paid handsomely, it is in a sheared zone or fault fissure, with an orebody intimately

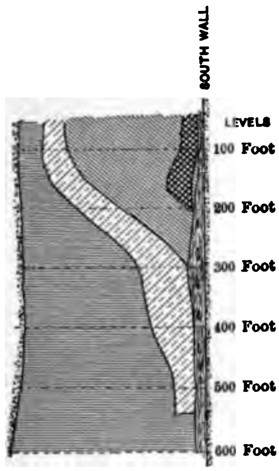


FIG. 88. – CROSS-SECTION OF TYEE OREBODY, VANCOUVER ISLAND, B.C. OREBODY CROSS-HATCHED; LIGHT-COLORED AREA IS SCHIST

connected with a sedimentary series included in the Vancouver Island crystalline rocks of Dawson. This orebody has a proved length of about 2700 ft., a mean width of about 20 ft., the maximum being 50 ft. of clean ore, and a depth of 150 ft., with crushed and striated boulders of ore to greater depths. The orebody is associated with a wide belt of graphitic schists, and the average composition of the ore from 220,000 tons shipped is 4.5 per cent copper, 3 oz. silver, and 0.14 oz. of gold per ton. The ore also carries 7 per cent zinc, 38 per cent barite, 12.5 per cent iron, and 12.5 per cent silica. The top of the orebody is covered by glacial débris and vegetation, and there is nothing to distinguish the

[1] "The Copper Deposits of Vancouver Island," *Transactions* A. I. M. E., vol. xxix, p. 483; *Engi* [illegible] *Journal*, 1900, April 21, May 5, July 14.

outcrop. It was only found after a forest fire had swept the ground at a point where the drift was absent. There is no grading off of ore into country rock, and the wall rocks carry no barite. There is no low-grade ore. The orebody is cracked and is full of slickensided surfaces.

The one orebody so far known is practically worked out.

The Britannia Copper properties are situated at an altitude of 3500 ft. on Britannia mountain, on the east side of Howe Sound, 28 miles from Vancouver. The orebody lies in a shear zone in altered schist, the zone running nearly east and west, dipping 30 to 62 deg. south. In this ore-bearing zone the schist is replaced by reticulating bands of quartz. Pyrite and chalcopyrite, with small amounts of galena and blende, occur in small and variable particles and bunches through both the quartz and the altered rock. The ore zone is more than 400 ft. wide and is traceable over several miles. On the Britannia claims ore is exposed in a cliff — the Mammoth bluff — more than 100 ft. high. The best ore is said to average 28 per cent copper, with about $2 per ton in gold and silver, and carries 62 per cent silica. Concentration of the ore is difficult owing to the nature of the rock, and results up to the end of 1906 were unsatisfactory, the concentrate carrying less than 4 per cent copper and about 40 per cent silica. The ore is smelted at Crofton, B.C., mixed with magnetite ore from the Mt. Andrews mine, Prince of Wales Island, Alaska.

The Texada Island copper deposits are at the north end of the island near Van Anda and the rival settlement of Marble Bay, a half-mile away. At the present time there are five working mines, three of which are shipping ore; namely, the Cornell, Copper Queen, and Marble Bay — all three situated close to the town of Van Anda. The town is about seven miles south of the extreme northern end of the island, and the Loyal mine lies some three miles north of the town. On the west coast directly west of Van Anda are the iron-copper mines owned by the Puget Sound Iron Company.

The ore deposits all occur along the contact between an intrusive body of diorite and altered limestones. The limestones of this end of the island are all marbles and lie close to a mass of granite. The diorite occurs in dikes running out from a main mass, and the ore is found impregnating garnet, particularly where the dike feathers out, and the fissure is prolonged in the garnet rock adjacent to the white marble. The orebodies are comparatively short, but have proved continuous in depth. The Cornell mine is 540 ft. deep and shows an

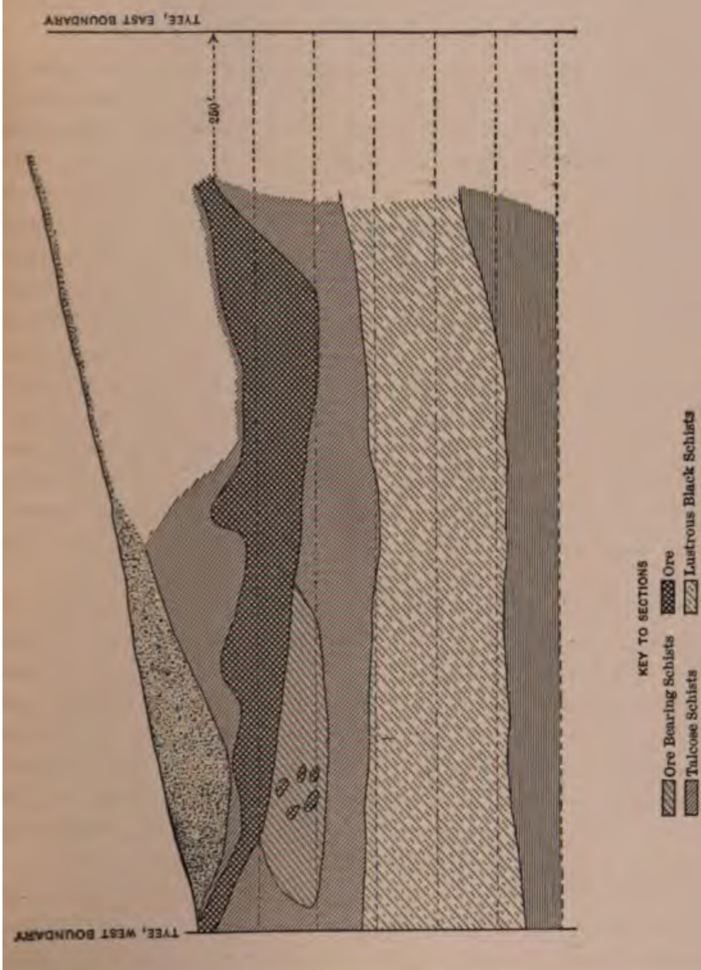


FIG. 89.—LONGITUDINAL SECTION, TYEE MINE, MT. SICKER, VANCOUVER ISLAND, B.C.
(FROM COMPANY'S REPORT)

ore shoot over 200 ft. long, the ore consisting of bornite and some copper pyrite scattered through a garnet gangue.

The Copper Queen mine has a vertical shaft 500 ft. deep and winzes to the 780-ft. level. The ore at the 680-ft. level is high in gold, averaging about an ounce and a half, together with about 5 per cent copper, as shown by the smelter receipts.

In the Marble Bay mine, the orebody is a pipe some 70 ft. long and from 20 to 50 feet wide, which was continuously worked from the surface down to the 600-ft. level. Below this point the orebody is thrown by a cross fissure and opens out on the 780-ft. level into a vein-like shoot that is from 2 ft. to 20 ft. wide and some 200 ft. long. The shipments average about 100 tons a day of ore that carries 7.79 per cent copper, $12 to $15 in gold, and 6 oz. in silver. The ore contains 39 per cent silica, 22 per cent lime, 5 per cent alumina, 5 per cent iron, and 3 per cent sulphur, in the form of garnet and other silicates.

The Commodore mine lies in the center of the north end of the island. The ore is base, but no shipments are being made.

On *Observatory Inlet* there is a remarkable deposit on the stream known as Bonanza creek. This deposit consists of very hard and very dense chalcopyrite ore, so hard that it rings under the hammer. This ore forms the surface, under a coating of moss beneath a forest vegetation, for a width of some 300 ft. and for a length of 1½ miles. On the surface it will average 10 per cent of copper; at 5 ft. in depth the ore has decreased to 5 per cent in copper, and at 15 or 20 ft. in depth the copper is gone. The ore occurs as a mantle over the greenstone, which carries disseminated pyrrhotite, pyrite, and a little chalcopyrite, and it is presumed that these sulphides alter to copper sulphate solutions, and travel along the surface underneath the moss and other vegetation, and as the solution cannot form glance in the presence of air and vegetable remains and the strongly reducing organic acids derived therefrom, the copper sulphate is reduced to chalcopyrite, which coats or mantles the rock for a foot or two, the lower limits of the chalcopyrite being irregular and extending down into a somewhat irregularly pitted surface. The rock is not sheared, but it shows occasional short gash veins of quartz. The rock is normal, fine-grained, and fresh, and is so dense that it sometimes resembles a mudstone. The Union Jack mine, also on this inlet, shows a good body of ore that persists in depth. The Vancouver series consists mostly of greenstone formed from various basic eruptives and occasional patches of limestone, the whole being grouped by Dawson as the Vancouver series.

The Skeena river copper deposits at Bornite mountain (Ptarmigan and others) proved unpayable and are idle. Other deposits near the head of the river are low-grade and of doubtful value. On the Copper or Zymoetz river, one of the headwaters of the Skeena, there are good but undeveloped prospects at about 54° 40′ north lat. and 127° 35′ west long. on the contact between the coastal granite mass and the complex of volcanic rocks to the east. There are two localities, both south of Hazleton, the head of navigation, and near the located line of the Grand Trunk Pacific.

Northwest Territory

Copper mines of the Kristiania type occur on the Upper Yukon, a few miles west of White Horse Rapids, 60 deg. 40 min. north lat., 135 deg. west long.

The deposits occur in a narrow terrace at the base of a mountain range, consisting chiefly of limestone. This base is a granite plateau which, according to Stretch, underlies limestone. A few patches of limestone remain on the plateau, and the ores occur at the contact of the two rocks, or in seams of varying size in the granite. Two varieties of ores occur: (1) large masses of specularite or magnetite, carrying copper pyrite; (2) outcrops of smaller dimensions, in which the ore is bornite with a little chalcopyrite. Many of the deposits are connected with east and west seams penetrating the granite, but nowhere is there evidence of massive vein-structure. Large orebodies were opened up in 1906.

At all the localities epidote and lime garnets are present. The bornite contains some gold and silver, and a little molybdenite is also found. Dikes of granite occasionally cut the limestone.[1]

Newfoundland

The copper deposits of Newfoundland occur on the eastern side of the island, on the shores of Notre Dame bay. The accompanying index map (Fig. 90) shows the location. Though classed as copper mines, the deposits are more properly designated as pyrite deposits, and derive their chief value from the fact that they are useful in acid-making. Only two deposits are at present being worked, viz. the Tilt Cove

[1] "Notes on the White Horse Copper Belt." *Engineering and Mining Journal*, September 8, 1900.

deposits, belonging to the Cape Copper Company, on the north shore of Notre Dame bay, and the Pillys Island deposits on the west end of the bay.

The deposits are all of the familiar Huelva type, being thick, lenticular orebodies of cupriferous pyrite inclosed in tilted bands of slates with interstratified dolomites, serpentines, and diorites. The rocks are recorded by Murray as Paleozoic, and are intruded by masses of granite,

FIG. 90.—MAP SHOWING LOCATION OF COPPER MINES OF NEWFOUNDLAND

forming bands, with an east and west course, the largest of whi[illegible] tends along the north side of Notre Dame bay a distance of [illegible] two from the shore. The inclosing rocks are corrugated and fo[illegible] chloritic slates or schists, carrying seams of serpentine, and cut by [illegible] compact greenstone, regarded by the N[illegible] volcanic ash and diorite. The orebodie[illegible] and apparently conformable to the schistosity, occurring, especially in the cases of folds, where stringers and veinlets run out along small faults and cracks.

The orebodies at Tilt Cove run north and south, three of them being known. The old or east mine is an orebody 200 × 300 × 120 ft., wedging at a depth of 120 ft. Another mass 4 ft. thick lies but 86 ft. to the west, and a third 10 ft. beyond. Another orebody is from 22 to 35 ft. thick. The dip is from 45 to 50 deg. to the northeast. The ore consists of pyrite with close-grained yellow chalcopyrite, carrying 4 per cent copper and 1½ dwt. gold. The ore is incased in soft slates on the hanging wall and adjoins the so-called hard diorite on the foot-wall. The larger orebody is dislocated by a clay-filled fault 6 ft. thick. The outcrop shows nearly fresh pyrite, with magnetite in small specks and large masses scattered through the pyrite. A distinctive feature is the large amount of steatite casing the orebodies, especially in the deeper workings. The Tilt Cove Company mined 54,253 tons of 3.3 per cent copper ore in 1902, yielding a net profit of $239,000.[1] The East mine at Tilt Cove yielded 1860 tons of 3.25 per cent ore in April, 1905, and the south lode, 1977 tons of 3.75 per cent ore.[2]

The orebodies at Tilt Cove run north and south; the main orebody is 200 ft. long and 75 ft. thick. Another lens about 4 ft. thick is found 86 ft. to the west, and 10 ft. beyond still another, 22 to 36 ft. thick. The dip is 40 to 50 deg. northeast. The footwall is the so-called diorite. The ore is dislocated by a clay-filled fault 6 ft. thick.

The outcrop shows pyrite and magnetite; the latter is in small specks and large masses.

The Tilt Cove Company mined 54,253 tons of 3.3 per cent copper ore in 1902, and yielded a net profit of $239,540. Three orebodies are worked: the old, or East Mine, the New South lode and the West mine, and the South lode.

[1] *Report* of the Geological Survey of Newfoundland, p. 118.

[2] ... deposit in Garland's presidential address, *Transactions* ... vol. iv, 1895–1896, p. 208.

XVI

COPPER DEPOSITS OF MEXICO

MEXICO ranks second among the copper-producing countries o world. Its deposits are scattered over many states; but the largest r are in Sonora, the northwestern state of the republic. The peni of Lower California contains the well-known Boleo mine, nearly opp Guaymas. Chihuahua has several producing mines, and various o occur in Coahuila, Durango, Pueblo, and Chiapas.

The copper producers of Mexico, named in the order of relative importance, are as follows:

The Greene Cananea Copper Company.
Boleo Copper Company.
Moctezuma Copper Company.
Teziutlan Copper Company.
Guggenheim Exploration Company.
Dolores y Annexas.
Panuco Copper Company.
Jimulco Copper Company.
Chiapas Copper Company, Santa Fé mine.
Aguascalientes Metal Company.
Rio Tinto Mexicana (Terrazas, Chihuahua).
Mendoza y Cia (Barranca del Cobre, Chihuahua).
Las Vigas mines, Chihuahua.
Clemente Ham (Promontorios, Alamos, Sonora).
Irogoyen Hermanos y Cia (Huetamo, Michoacan).
Quintera (a silver mine in Alamos, Sonora).

In character the deposits present a considerable variety. In gen they are associated with acidic igneous rocks, granites, and rhyol rather than the basic rocks which are characteristic of most European mines.

The great central plateau of Mexico and the mountain regions car from it along its eastern and western borders are composed of igne

FIG. 91.—INDEX MAP SHOWING LOCATION OF COPPER MINES OF MEXICO

rocks breaking through or resting upon Cretaceous limestones, practically all the great ore deposits which yielded the enormous tre taken by the Spaniards, and which are still productive today, occ these rocks. While the great silver-lead deposits are in the lime series, the gold districts of the western Sierra Madre are main andesitic rocks, cut and covered by rhyolitic material. To the s west this plateau country ends in the volcanic region of Colima an valley of the City of Mexico. A region of more diversified gec structure is found to the southwest. On the road to Oaxaca f sedimentary rocks appear resting on a complex of crystalline sc and these rocks form a belt running along the mountain region fr point about 18 miles west of Oaxaca to the region west of Balsas riv

According to Aguilera,[1] the copper deposits of Mexico generally in acid granites and rhyolites of Tertiary age, or as contact deposits a neutral rocks. According to this author, gold-bearing copper veins in aplites and Tertiary diorites in the Mina district, Guerrero, ai Cacoma, Ameca, and Jalisco. The veins consist of chalcocite, ch pyrite, and pyrite in a gangue of quartz, with some zeolite. At an locality in Guerrero, namely, Cerro Blanco, Ajuchitlan, there are carrying chalcopyrite, with argentite and other silver minerals, copper glance with a quartz gangue. These veins occur in granit

At the well-known town of Ojo Caliente there are veins car sulphide of copper, iron and silver, cutting aplite.

Fissure veins in rhyolite, with glance and chalcopyrite as pri minerals, occur in Chihuahua.

Contact deposits are frequent (Puertocitas at Cananea; Jim Chih.; San Jose, Tam.; and in Chiapas); ores also occur in no limestone (Jimulco and Mapimi), in impregnated sandstones (Las Vi and as impregnations of flat-bedded igneous tuffs and conglome (Boleo) and mixed with other metallic sulphides bedded in slates (Teziutlan), and as a by-product of silver mining (Quintera).

Sonora

The *Cananea district*, the most important copper region of Me lies about 40 miles southwest of Bisbee, Arizona.

The Cananeas, like most of the mountain masses of Arizona Sonora, are a group of isolated mountains rising out of the arid p

[1] "Distribution of the Mineral Deposits of Mexico." *Transactions* America stitute of Mining Engineers, vol. xxxii, p. 571.

Mexican frontier. The range runs northwest and south-
parated by a low gap into two parts, a northern unmin-
and a southeastern group, the Cananeas proper. The

F PART OF SONORA, MEXICO, SHOWING LOCATION OF CANA-
EA, NACOZARI, AND OTHER COPPER DISTRICTS

ccur along or near the crest or divide of this range for a
ght miles.

The mountains are composed of the shattered and altered remains of Paleozoic limestones, intruded by great masses of porphyry, with white granite to the northwest and porphyrite and diorite to the north; the mountain flanks to the east are bedded volcanic tuffs, dipping generally away from the range and proving it to be an eroded volcanic center. The limestone, altered by contact metamorphism, occurs along a narrow northwest and southeast belt, the beds being usually steeply tilted to the northeast. To the northwest it forms bluffs and high ledges, being very resistant. Dikes and sheets of porphyry are intrusive in these altered limestones. The prevailing rocks of the district are igneous, and the bonanza orebodies occur in porphyry or the replacement quartzite in which the porphyry is intrusive.

According to R. T. Hill,[1] there is a continuous narrow fault zone running with the axis of the mountains and paralleled by accessory faults, constituting a narrow zone of fissuring or shearing. All the ore deposits are within this belt or south of it, and the alinement of the ore deposits is with this fault. The Greene Cananea Copper Company owns practically the entire district. The mines, beginning at the southeast end, are (1) Cobre Grande, (2) Capote Basin group, comprising the Esperanza, Capote, and Oversight, (3) Elisa, (4) Puertocitas group.

The Cobre Grande vein at the southeast end of the property is a fissure vein in quartz porphyry, striking north 65 deg. west, dipping northeast, with the porphyry altered by solfataric action and replaced by massive ore dotted with disseminated pyrite, and changed in the orebodies to glance. In June, 1906, a bonanza of high-grade massive copper glance was discovered in this vein south of the Cobre Grande mine. Ore was also found on the flat a half-mile to the southeast. These discoveries led to the formation of a new company, now owning almost the entire district. The lode runs directly toward the Democrata mine, three-fourths of a mile distant.

In the Capote district, drained by Chivatera creek, there are four great lodes and huge limonite outcrops. The following lodes are worked: (1) Democrata, the northernmost, (2) Veta Grande, (3) Esperanza, (4) Capote-Oversight to the south. These orebodies are all either in porphyry or in quartzite.

In the Democrata the orebodies are along a contact between a dike of diabase porphyry and a garnetized limestone. Two thousand feet to the west is the Veta Grande orebody. This, according to Hill, is 200 ft. wide, 1400 ft. long, and developed for 400 ft. in depth. It occurs

[1] "Cananea Revisited," *Engineering and Mining Journal*, August 29, 1903, p. 311.

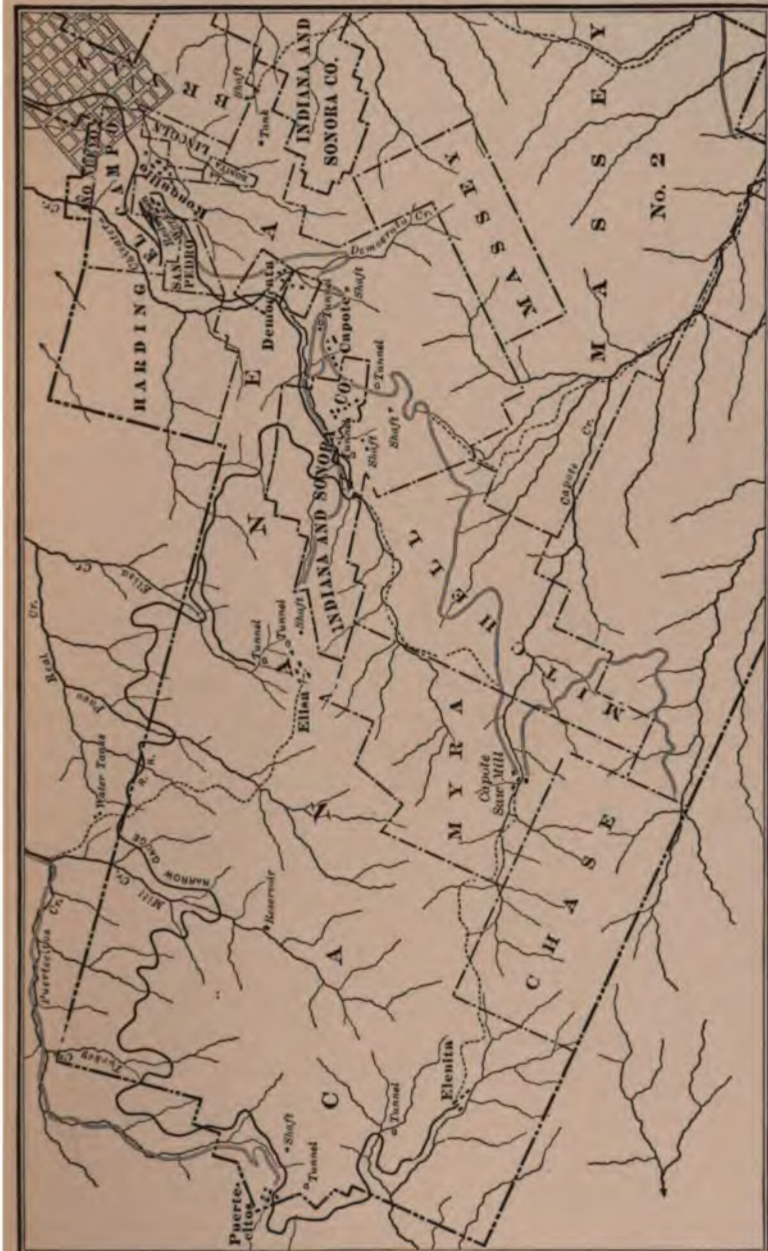


FIG. 93.—MAP OF COPPER PROPERTIES AT CANANEA, SONORA

FIG. 94 — CAPOTE BASIN, MEXICO, FROM VICINITY OF COBRE GRANDE, NO. 9

on the contact between a quartz porphyry dike and the belt of contact metamorphosed limestone, lying between this and the Democrata. The copper ore, mainly glance and pyrite, occurs in the porphyry; oxidized ores, mostly native copper, occur in the upper levels. Complex lead-zinc-copper sulphide ores also occur. A bonanza body of 10 to 12 per

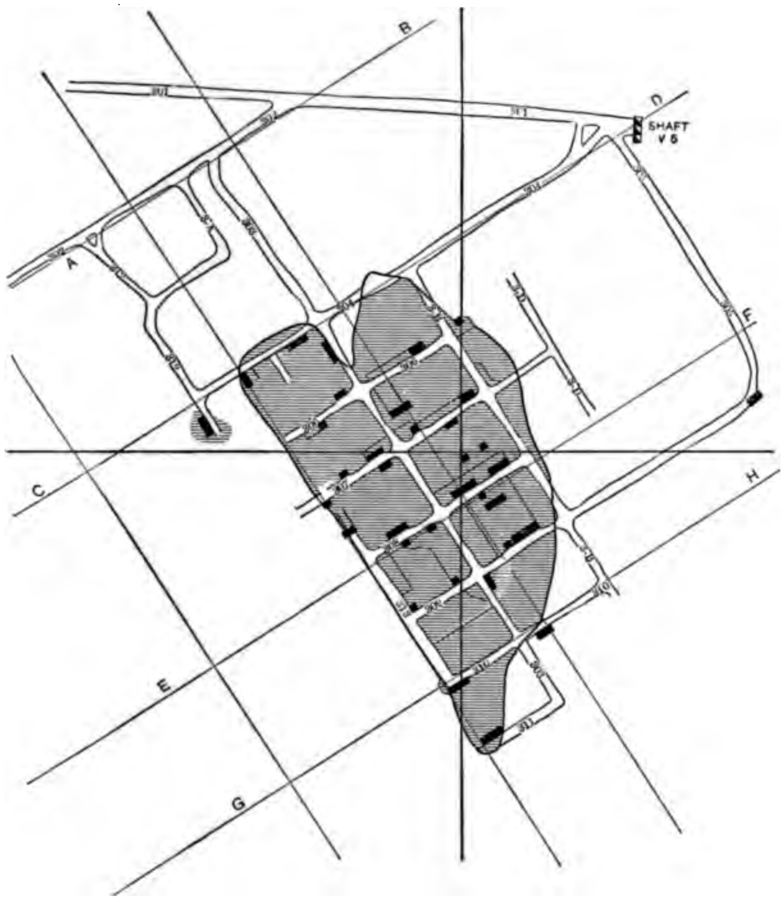


FIG 95.—MAP OF THIRD LEVEL, CAPOTE MINE, CANANEA

cent copper measured 68 × 410 ft., with 150 ft. of 3 to 6 per cent ore alongside on the third level.

The Capote-Oversight lode lies 2000 ft. south of the Veta Grande, with the Esperanza vein between. The great orebodies of each of these

two mines have an offset of about 80 ft. between them, though c
same lode. The Capote orebody is 800 ft. long, 225 ft. wide a
north end, 165 ft. in center, and 186 ft. at the south end. The
sight is larger.

To the south the rocks occur in the following order: (*a*) q
porphyry, (*b*) 300 ft. of altered and mineralized limestone, (*c*) qua
of the footwall mountain.

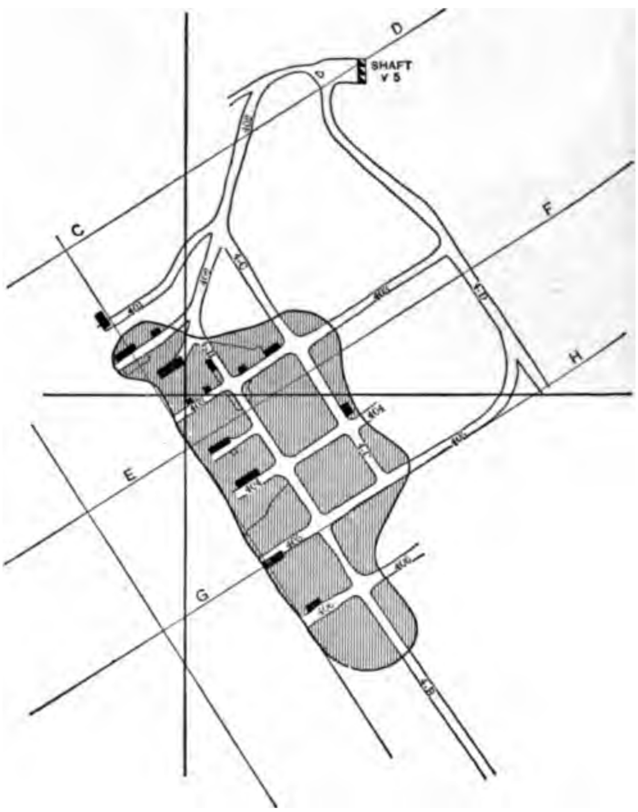


FIG. 96. – MAP OF FOURTH LEVEL, CAPOTE MINE, CANANEA

The Massey orebody is the largest yet discovered. At all
mines the first-class ore is an altered and bleached, pyritized porpl
secondarily enriched by chalcocite. There has been movement,
plastic dark-colored clays represent fault movement and alter
products. The outcrops at this mine showed slight indications

bonanza beneath; the porphyry is without mineralization, gossan, or malachite staining. In the Capote orebody ore occurs in shattered quartzite as well as porphyry, though the latter rock is the more favorable one. The ore, like that found in the Butte, Mont., mines, is soft; the ground swells; and though closely timbered the workings cannot be kept open, especially where solfataric action has altered the porphyry to a putty-like clay, dotted with pyrite grains formed from its iron. This clayey matter is largely sericite, and causes trouble in concentration.

The Elisa lode lies about 1500 ft. northwest of the Capote. It is a bedded vein 20 ft. wide in a limestone block between the quartzite footwall of the Capote and the red porphyry to the north. The ore consists of irregular bodies of chalcopyrite in a fault fissure.[1]

The Puertocitas and Elenita mines lie four miles northwest of the Elisa, with several outcrops of garnetiferous ore between. The orebodies occur in mineralized beds interstratified with garnetized-epidotized limestones, and are typical contact metasomatic ores; in some beds, a complex intergrowth of calcite, quartz, chalcopyrite, galena, and blende is seen. The conditions in this district closely resemble Morenci.[2]

According to Hill, the Sonoran province, so noted for copper deposits in Arizona and Sonora, extends southward through Sinaloa and Michoacan, etc., on the west of the Cordilleran province. This view needs confirmation by further research; for, although the three largest producers are in the Sonoran region, other copper mines, together with many as yet but partly developed, occur in the central or eastern part of Mexico.

The Moctezuma district in central Sonora, Mexico, has many partly developed copper properties, though Nacozari is the only producing camp. The deposits exhibit considerable variety of character. At Promontorio, in the mountain ridge, separating the valley of the Yaqui river from that of the Moctezuma on the west, there is a large deposit recently examined by W. O. Crosby.[3]

The Promontorio mine is west of the junction of the Bavispe and

[1] R. L. Austin, *Transactions* American Institute of Mining Engineers, vol. xxxiii, p. 1070.

[2] See W. H. Weed, "Ore Deposits of Cananea." *Transactions* American Institute of Mining Engineers, vol. xxxii, p. 428; *idem*, "Ore Deposits near Igneous Contacts." *Transactions* American Institute of Mining Engineers, vol. xxxiii, p. 715; A. A. Steel, *Engineering and Mining Journal*, September 26, 1903; M. Schwerin, *Engineering and Mining Journal*, September 26, 1903, p. 463.

[3] "Travers-Durkee Coppers," published by the Company, 1906.

Aros rivers, 30 miles southeast of Moctezuma. The mountain in which the ore deposits occur is 4000 ft. in elevation, and consists largely of granitic rocks, chiefly monzonite and diorite, with isolated patches of a former capping of gray and crystalline cherty limestone. The range is flanked by a thick mantle of volcanic dacitic tuffs, covered in the valleys by basalt. The general conditions resemble somewhat those at Cananea, but the limestones are not ore-bearing.

The granitic rocks are traversed by a fault zone trending northwest and southeast, parallel to the range and to the sedimentary contact. The orebody occurs in a shear zone composed of innumerable small fissures.

At the Promontorio mine the shear zone is 50 ft. in width and dips northeast at 70 degrees; it outcrops for 1000 ft. The ore occurs as a sulphide replacement and impregnation of the crushed and altered rock of this shear zone. The granite footwall is impregnated with sulphides, the rock carrying, it is said, 2 per cent copper. A zone of high-grade bornite ore occurs at the hanging wall, and the values gradually fade off toward the footwall.

The first 25 ft. of this zone of high-grade ore averages, according to Crosby, 19.64 per cent copper, the next 25 ft. 5.28 per cent, with $1.00 to $3.00 in gold. The diorite hanging wall is impregnated with sulphide, mostly bornite, and averages about 1 to 2 per cent copper.

The ore smelted at Douglas, Arizona, yielded 22 to 27 per cent copper, 3.1 to 3.7 oz. silver per ton, $2.00 gold per ton, 8 to 9 per cent iron, 11 to 14 per cent sulphur, and 45 to 55 per cent insoluble.

The Transvaal Copper Company owns and operates mines about 30 miles a little west of south from Nacozari and 125 miles south of Bisbee. The mines are in a mountain range lying between the Cumpas (or Moctezuma) and Sonora rivers, the town of Cumpas being 12½ miles northeast. The region is covered by extrusive volcanic rocks, mostly rhyolitic, cut by mineralized porphyry dikes, running north-south and dipping east, and the orebodies are capped by iron gossan. Beneath the oxidized ores, glance, bornite, and chalcopyrite occur. The ores are low-grade, averaging 3 to 6 per cent copper in the workings according to recent reports, with 2 to 6 oz. silver per ton. The only information available is that supplied by the company.

There are numerous other copper deposits in Sonora, mostly as yet in the development stage. El Cobre property is 12 miles north of Bavispe, in the Moctezuma district, 60 miles from Yzabal, on the Nacozari railroad. The orebodies occur in limestone near the contact with intrusive bodies of granite and porphyry, which in part underlie the sedimentary rock. The deposit shows large gossan outcrops.[1]

Alamos. — The Alamos district has long been known as a center of production for silver ores; but according to Forbes Rickard,[2] copper is destined to be the chief product. The Quintera mine has been for some years a producer of copper, it being a by-product of the silver ores.

The Piedras Verdes deposit is a ferruginous impregnation zone, not less than 350 ft. wide, traceable for two or three miles. Its course is northeast, parallel to the trend of the dacite and rhyolite belt. There are six veins running at right angles to the massive igneous rock, and possibly filling contraction cracks. Their course is 57 deg. north to 74 deg. west, with flat south or north dip. Three veins vary from a few inches to 2.5 ft. in thickness; the others are smaller and undeveloped. These veins abut against or end against a mass of quartzite 300 to 400 ft. wide, running at right angles to veins. The native workings extracted nests of rich ore only. Below the oxidized zone the ore shows scattered pyrite and some chalcopyrite, and narrow seams of cuprite and native. The ores average 2 per cent copper for the center zone.

The Reina del Cobre mine lies 15 miles northwest of Alamos. The vein consists of a shear zone in crushed shale (Cretaceous?), the filling being of fragments loosely cemented and incrusted by copper minerals and quartz. The orebody is 55 to 60 ft. wide, and about 500 ft. long, and in surface excavations will average 2 to 3 per cent copper.

"It belongs to the class of veins in which leaching at the lower zone of the reopened vein has brought about conditions favoring the deposition of copper in the upper or surface portion of the same deposit. It is with such brecciation and recementation of the vein filling that copper orebodies"[3] often occur.

El Cobre mine is about 35 miles northeast of Alamos. The ore occurs in a fissure vein in massive andesite. The ore shoot is flat and from 9 to 12 ft. thick and 80 ft. long, averaging about 6 per cent, with extremes of 2.6 per cent to 10.1 per cent. A porphyry dike followed by the workings is only productive where veins angle into it.

Nacozari or Moctezuma District. — This locality lies 75 miles south of the international boundary, in the Moctezuma valley. The region

[1] Manuscript report to L. H. Taylor, Jr.

[2] "Copper Deposits in Sinaloa and Northern Sonora." *Engineering and Mining Journal*, July 21, 1904, p. 97.

[3] Forbes Rickard, *loc. cit.*

is one of irregularly distributed hills of volcanic breccia and t
andesitic habit, with sharply folded limestones near Nacozari.[1]

Though the district is extensive, and embraces many copper erties, the only producing mines are those of the Moctezuma C Company (Phelps, Dodge & Co.), the ore coming mainly from Pilares mine, named for the pillars of gossan which crown Paulina hill, in which the mine is located. The rock of this hil fine-grained andesite altered and sericitized, showing no recogni basic silicate.

At and near the main tunnel the rock consists largely of se chlorite, and some calcite colored reddish-purple by microscopic h tite, magnetite, and ilmenite. It is an eruptive breccia, the fragı and cement being of similar character. The "Y" shaft is in a that is probably a monzonite, though it resembles a rhyolite, la structure and quartz phrenocrysts. Though apparently massive homogeneous, it reveals a fine breccia structure in thin section is highly silicified and sericitized with secondary quartz veinlets interlocking grains. Dikes of dense dark diabase of even holo-cr line texture traverse this acidic rock.

The ore is a coarse breccia of altered monzonite cemente pyrite, chalcopyrite, and quartz, with mere traces of zinc and no The pyrite and chalcopyrite are primary; bornite and chalcop the first most abundant, are secondary. The gossan is spe hematite, a common derivation of limonite in the arid provinces.

The ore is peculiar, being composed of splinters and thin cı shell-shaped slabs of rock with a brass-yellow cement, a vene bright blue bornite and glance coating pyrite and chalcopyrite. R boulders of rock free from ore occur in the orebody, and are the ı of chemical alteration of the rock, the concentric shell or coats b ing off and being cemented by ore (see Fig. 97).

The orebody is neither a vein, bed chimney, nor stock. accompanying figure (Fig. 98) shows a sketch of the main drif the 400-ft. level, the squares representing roughly the areas st out. The whole mass of the hill is altered monzonite impregı by copper and pyrite, but too low-grade to work. The payable bodies occur where fracturing has permitted a secondary gatherii material into an unusual concentration of ore in the southeast pa the mine. One fracture plane is an east-west fault, a singularly (and smooth nearly vertical plane of movement, devoid of clay sel

[1] S. F. Emmons, *Economic Geology*, vol. i, p. 629.

and sometimes showing several closely spaced fissures, 21 in less than two feet showing in one place. There is an abrupt change from solid and lean monzonite to typical breccia and pyrite, appearing first in a thin vertical seam, then copper ore, and then a gradually increasing amount of quartz and less sulphides.

The second plane of movement crosses the first at nearly right angles. It shows a thin dark clay selvage, which when followed passes into a dike of very dark diabase, 6 to 15 ft. thick. This forms the eastern limit of the ore.

FIG. 97.—ORE FROM LOS PILARES MINE, NACOZARI, SONORA, MEXICO

The orebody limited by these two planes has been worked for a length of 1300 ft. along an arc whose chord is 800 ft. across. The yield up to 1906 has been 600,000 tons of ore.

The pay ore extends from a little below the 100-ft. level down nearly to the 500-ft. level, becoming leaner at this depth. Three per cent ore is at present the lowest grade ore that can be profitably mined. The amount of lower grade in the hill must be enormous.

The Pilares dike thins out to a mere seam upward (60-ft. level). The mass of the hill is cut by many seams and fractures. The breccia is regarded by Emmons as due to fracturing; but it is not friction breccia, shattering having taken place not between the fissure walls, but at some distance outside, acting on the rock decom by heated solutions and gases circulating along preëxisting planes.

The conclusion is reached that the location and extent of tł channel are due to later fracturing, which admitted surface water led to secondary enrichment. There has been movement sinc diabase dikes were intruded, as shown by the squeezed and draw dikes. Water occurs only at the north intersection of the dike b 500-ft. level, and it appears that the general course of the dikes place to look for ore.

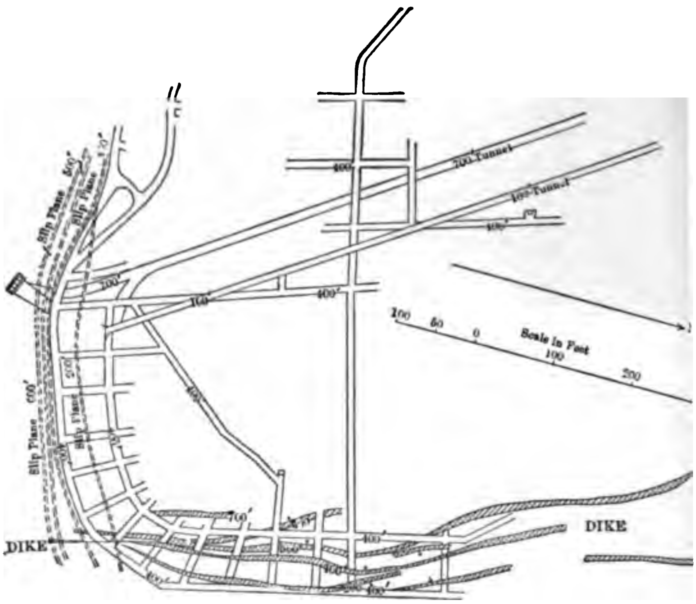


FIG. 98. – LOS PILARES MINE. PROJECTION OF MAIN DRIFTS IN 400-F(LEVEL, WITH INTERSECTIONS OF DIKE AND SLIP-PLANE. (EMMONS

This ore deposit is analogous to the orebodies of disseminatec cupriferous pyrite along shattered zones in porphyry at Brig Utah, and Ely, Nevada.

There are many promising but as yet non-productive c(properties in Sonora. The Verde Grande, 34 miles northwe: Hermosillo, is a contact deposit, with oxidized ores in garnet wollastonite, near a granite contact. The beds are 10 to 30 ft. and dip east at 35 to 45 deg.

Lower California

Boleo. — The Boleo mines are the second largest copper producers of Mexico. The mines are on the east side of the peninsula of Lower California, near Santa Rosalia, and almost opposite Guaymas. According to Fuchs, the district is part of an extensive plateau built up of beds of trachytic and andesitic volcanic tuffs, which slope gently toward the Gulf of California, and are of Miocene age. The mesa runs back to a range of trachytic peaks, and in the vicinity of the mines is capped by an extensive basalt sheet; it is trenched by four deep gorges and dominated by several rounded hills.

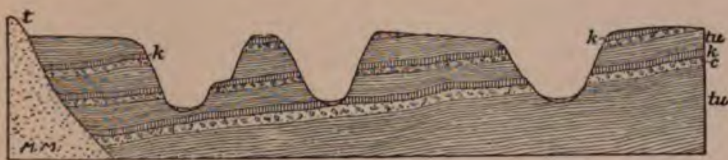


FIG. 99.—CROSS-SECTION OF COPPER-BEARING BEDS AT BOLEO, MEXICO. (De Launay.) *t*, TRACHYTE; *tu*, CLAY; *c*, CONGLOMERATE; *k*, COPPER FLOAT

Three of the beds carry copper ore. The lowest is 1⅓ to 10 ft. thick, and the middle 2⅔ to 8½ ft., while the uppermost averages 3¼ ft. thick. The beds are formed of a decomposed conglomerate of clayey volcanic tuff of lilac-gray color. This ore consists of cuprite, atacamite, azurite, malachite, chrysocolla, and crednerite, and is mostly earthy and not crystalline. Covellite and glance occur in the lowest beds. It forms small masses or concretions and granules scattered through the clayey matrix. The tuff contains from 0.1 per cent to 6 per cent sodium chloride and the ore carries 15 to 26 per cent CuO, and is remarkable for its high percentage — 7 to 24 per cent — of manganese oxide, with 4 to 12 per cent ferric oxide.

At the bottom of each ore-bearing bed the ore is concentrated in a layer 15 to 20 in. thick.

The middle bed is especially silicious near a fault fissure that dislocates it, and is supposed to have been the channel of a former hot spring. This bed contains the rounded concretions or "boleos" (balls) of oxide and carbonate, which gave the name to the place.

The mines produced 10,480 metric tons of copper from 230,490 tons of 4.56 per cent ore (net) in 1903. According to De Launay, the ores are due to sedimentation, aided by vein-forming waters emerging during tectonic movements, forming the conglomerates, with chemical] cipitation of pyrite, gold, copper, etc., and simultaneous depositior this material with the pebbles of the conglomerate.[1] To the writer evidence of silicification and the greater permeability of the conglomer beds, resting on impermeable tuff clays, indicates a circulation of mii alizing waters (hot-spring action?) after sedimentation.

The Boleo company, having only oxidized ores whose treatment the blast furnace entails rich slags, uses gypsum (dehydrated) to : phurize the ore. It is mixed with fine coke dust and briquetted.

Remarkable manganiferous copper deposits occur in the vicinity Muleye, in Lower California. They outcrop about 66 miles noi northwest of the town, in veins cutting Tertiary trachytic tuffs. In undecomposed state they carry manganiferous and cobaltiferous cop glance in chalcedony, with some gypsum. Farther east true m ganese veins occur, with a gangue of quartz and gypsum and conti ing psilomelane carrying 0.38 to 1.2 per cent of copper.

CHIHUAHUA

The *Las Vigas* copper mines are about 1½ miles north of the Conc river and 70 miles northeast of Chihuahua, near the Chihuahu Pacific Railway line.

The country between the Rio Grande and Chihuahua city is a par the Mesa Central, and shows numerous narrow isolated mountain ran with intervening pocket-valleys or wide expanses of undulating pl The ranges consist of folded limestones, usually in clearly defi anticlinal folds. These rocks occasionally show also in the plains, are more commonly concealed by soil or débris. Occasionally mountains are capped or flanked by masses of dacitic porphyry, rai massive, commonly tufaceous, and showing a rude bedding such characterizes the deposits of fragmental ejectamenta from volcan The limestones are Cretaceous and the tuffs of later age.[2]

The copper veins occur in low ridges east of a flat plain. The ve are impregnated sandstone strata, forming part of a continuous sei of Cretaceous rocks, several thousand feet thick, and on edge.

Three ore beds occur (Fig. 100). They are beds of sandstone a shale from 4 to 7 ft. wide and coursing north and south, impregna

[1] Translation in *Engineering and Mining Journal*, April 4, 1903, "Copper Dep at Boleo, Lower Cala."

[2] W. H. Weed, "Notes on Certain Mines of Mexico." *Transactions* American stitute of Mining Engineers, vol. xxxii, 1902, pp. 369–443.

with copper carbonates, oxides, and sulphides. In addition to the three main ore carriers, there are several cross fractures and veins which fault the beds and carry little bunches of copper ore in calcite gangue. The "vein-walls" are sharply defined by shale; but bands of shale included in the vein are mineralized. There is little true gangue mineral, so far as observed, the silica being merely that of the original sandstone.

An average sample from a large number of cuts across the vein gave: Silica, 74.4; iron, 8.5; lime, 2.0; copper, 5.2 per cent; gold, 0.6; and silver, 1.45 oz. per ton.

The surface ores consist mainly of malachite, but at a depth of 50 to 100 ft. glance ore is encountered — a black sandstone in which the quartz grains are coated and cemented by rather earthy-looking copper sulphide, the ores averaging 8 per cent. It is impossible to say whether any replacement of the quartz has taken place; but the selected ore shipped carries from 20 to 30 per cent of copper. That it will pass into chalcopyrite in depth is indicated by occasional specks of that mineral in it.

FIG. 100. — CROSS-SECTION OF LAS VIGAS DEPOSITS, CHIHUAHUA, MEXICO

Origin of Veins. — These ore-bearing strata were impregnated because the rocks were extremely porous. Hot springs existed near by and formed deposits of tufa; and there may be some genetic connection between this and the copper seams, though it appears more probable that the springs are of very recent origin. The fault veins of gypsum, calcite, and copper that cross the main ore beds are clearly of later age. They cannot be, as was at first believed, the feeders for the main veins, carrying the mineral-bearing solutions out into the porous beds crossed by the fault, for the gangue of the two sets of veins is essentially different; moreover, the ore veins are, if anything, poorer near these cross fractures, and maintain high values far from them which would negative the hypothesis mentioned. These faults throw the strata from 8 to 30 ft. to the west, i.e. on the north side of the fault.

The main ore beds consist of sheeted or fractured sandstone, v malachite, azurite, and more rarely cuprite films, along the fractu The amount lessens at the borders until the rock is normal sa stone. The shale belts between the copper-bearing sandstone la carry much ore in films and nodules. Though there is little appa brecciation of the rocks, and no slickensides or clay selvages, it is dent from the occurrence of the ore along the fractures of the fissures that there has been some movement and shattering of rocks. Commonly the veins show a plating or sheeting of the sa stone. Below the influence of surface waters, at a depth of 42 ft., vein carries glance. It is here crossed by flat fractures — mere fil partly of gypsum and partly of calcspar, which occur 5 to 7 ft. a vertically and delimit the ore; that is, they show that the glance is result of descending waters. The interruption caused by such film only temporary; for rich ores occur below, but the sand-rock immedia below each fracture is relatively lean. The vein is sheeted by vert fractures into slabs ½ in. to 4 in., but mostly less than 1 in. thick, and gypsum films of fracture planes are from ¼ to ½ in. thick.

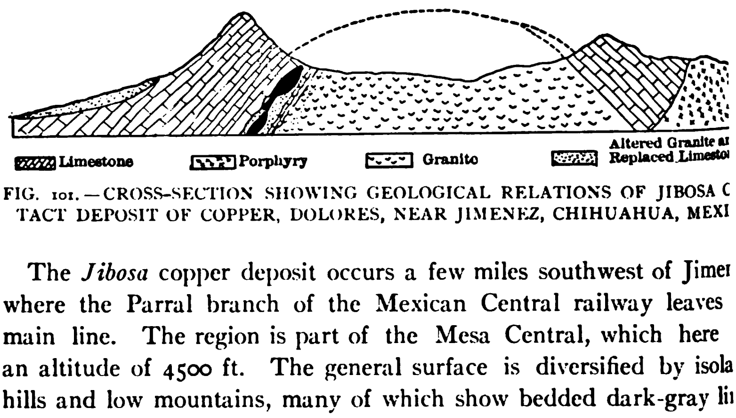


FIG. 101. — CROSS-SECTION SHOWING GEOLOGICAL RELATIONS OF JIBOSA C TACT DEPOSIT OF COPPER, DOLORES, NEAR JIMENEZ, CHIHUAHUA, MEXI

The *Jibosa* copper deposit occurs a few miles southwest of Jime where the Parral branch of the Mexican Central railway leaves main line. The region is part of the Mesa Central, which here an altitude of 4500 ft. The general surface is diversified by isola hills and low mountains, many of which show bedded dark-gray li stones. The group of hills in which the copper deposits occur con of limestones and shales cut by igneous intrusions. The north ridges are largely formed of massive rhyolite porphyry; but furt south the hills terminate in a nearly circular ridge of eroded limesto and shales, which seem to dip away on all sides from a central mass coarse-grained granite eroded into a basin or amphitheater.

The copper ores occur in a typical contact deposit of the Kristia type. As indicated in the accompanying diagram (Fig. 101), the li once arched over and covered the granite. The deposit follows ne of contact between limestone and granite, and the contact mena vary somewhat. Most frequently the limestone is converted massive garnet rock, more rarely (where the original limestone was) into coarsely crystalline marble. At the south end the deposit much black biotite and specular iron (hematite) and magnetite, ome epidote. The outcrop is often a mass of iron-stained quartz, hard and dense, and devoid of the honeycomb structure of gossan. nine workings show the ore in irregular bodies (some being 200 ft. and twice as long, while others are too small for exploitation) of oval cross-sections, lying in a mass of gypsum, calcite, and silica, en the partly altered limestone and the granite. The granite is d in successive regular shells or layers, seldom exceeding 5 ft. in less, which show varying degrees of oxidation. Nowhere were ore- s found in immediate contact with the granite. The irregular lime- walls of the deposit show plainly the effect of solutions acting upon ck, which is pitted, exhibiting on a large scale the etching produced acid solution on limestone. Clay walls, slickensides, and other ices of faulting are wanting. There is, therefore, no vein structure. orebodies consist of copper carbonate and oxides, and occur in a le of gypsum and calcite with much iron oxide. It appears prob- hat the original copper and iron sulphides were oxidized, and, re- ; with limestone, formed the copper carbonate now seen.[1]

h contact copper deposits, found at or near the contact between ic rocks and limestones, are of very common occurrence in Mexico. may be of the Kristiania type described by Lindgren, like those of itos, near Mapimi, or they may show later fracturing with definite and vein structure, accompanied by enrichment of the deposit. In rmer, the ores do not extend into the granite, but appear to be ements of the limestones. In both forms there is a very general ation of the copper ore with mosaic rock, of garnet, calcite, etc., d by the alteration of impure limestones. Where the deposit s in garnet rock, it is cupriferous; where it is in contact with pure ones or marbles, the lode is composed of pyrite or barren lode r. The Terrazas mine near Chihuahua is a contact deposit.

ZACATECAS

e Mazapil Copper Company is working the Aranzazu mine at pcion del Oro on a railway running south from Saltillo. The t is of the contact type and is enormous, covering several miles.

[1] Weed, *Trans.* Am. Inst. Min. Eng., vol. xxxii, 1902, p. 376.

Coahuila

Jimulco. — At a point 10 miles southeast of Jimulco (a few stations south of Torreon), "the mine of the Jimulco Mining Company is situated in a mountain range composed of Comanche limestone strata, between the vertically outcropping bedding planes, of which the copper carbonate stains may be seen over a considerable area. At one place, along a fissure dipping slightly diagonal to the vertical strata, there are great chambers, in one of which 30 per cent copper ore (carbonates and oxides), accompanied by a pulverulent specular hematite (62 per cent of iron), was found. No igneous outcrop is to be seen anywhere in the region; and it is obvious that the ore could not have been derived from the purely marine limestone constituting the country rock. Its only possible source has been circulating solutions from some concealed source within the great mass of mountains, upon the edge of which the mine is situated. Copper deposits, however, are exceptional within the Cordilleran province." [1]

Chiapas

Copper deposits about igneous contacts are found in many parts of Mexico, and several of them are profitably worked. The Santa Fé mine is a contact deposit of a remarkable type, whose only known counterpart is found in Sumatra.

The Santa Fé mine is situated 35 miles south of Teapa, Tabasco, and 51 miles from San Juan Bautista. The district is one of hills and gorges, the mine having an altitude of 1400 ft. The surrounding hills consist of limestone resting on slate, underlain by massive igneous rocks, "syenite" and "trap" according to McCarthey. The ore outcrops in high white cliffs of wollastonite (SiO_2 52 per cent, CaO 48.3 per cent), grading into schistose garnet-quartz rocks to the northeast, while in places elsewhere the wollastonite grades to quartzose ore and garnet rock.

The copper ore proper consists of argentiferous bornite, with associated free gold, tetrahedrite, chalcopyrite, and bournonite, with chimneys of oxidized ores. The values run 3 to 4 per cent copper, 6 to 8 oz. silver per ton, and \$6 to \$30 gold per ton.

The ore lies between the wollastonite and the igneous rock; it has a garnet gangue and appears to, in part, replace wollastonite. It forms solid bunches and plates, but is more generally in channels or irregular

[1] R. T. Hill, "Geographic Features of Mexico," *Transactions* American Institute of Mining Engineers, 1904.

courses a few inches to a few feet wide, and without definite walls. Orebody 400 by 1000 ft.; dip 70 to 80 deg.[1]

Guerrero

A large orebody of the Huelva type is found at La Dicha, in Guerrero, Mexico, 150 miles south of the City of Mexico, in the mountainous country south of the edge of the Mexican plateau, about 50 miles east of Acapulco. The orebody occurs in dark gray to light gray micaceous metamorphic schists, carrying quartzite bands, which are at times conglomeratic, thus proving their original sedimentary condition. The ore belt shows a more or less continuous outcrop for 4 miles, with thin (up to 10 ft.) but persistent stringers of primary ore — chalcopyrite mixed with pyrrhotite in mineralized schist. According to R. T. Hill, the ore belt is proved by natural and artificial exposures for 7700 ft. That author claims an average width of 12 ft. for the first 2100 ft., 88 ft. for the next 2700 ft. along the vein, and then a width of 61 ft. for the remainder of the distance. The ore consists of pyrrhotite, with chalcopyrite in streaks, bunches, and specks scattered through it. It sometimes incloses angular fragments of schist, proving that the vein, although apparently conformable to the schistosity, occupies a fault fissure. The zoisite, pyroxene, etc., of the Ducktown type have not been noted. The primary ore carries, according to the company's estimate, about 5 per cent copper.

Michoacan

Inguaran. — The copper deposits of Inguaran consist of veinlets and stringers of chalcopyrite in a quartz-mica-diorite impregnated with pyrite. Bornite and glance occur in small amounts. According to estimates made by various visitors, the orebody is quite low-grade, averaging between 2½ and 3 per cent. The ore must be concentrated as at Bingham, Utah, to be profitably mined. The district is remote from existing railroads, and although large sums of money have been spent on a 20-mile electric tramway and a mining plant, there is much to be done before the deposit can be ranked among the producing copper mines of the country. Similar deposits exist near Patzcuaro.

Durango

The Guggenheim Exploration Company owns a number of copper mines in various parts of the country. The Santa Maria y Annexas at

[1] Henry F. Collins, *Transactions* Institution of Mining and Metallurgy, vol. xii, p. 58.

Velardeña, in Durango, carries a copper-lead ore with precious metal values. It is, according to Austin,[1] a contact metamorphic deposit.

There are several other contact metamorphic deposits in Durango. The one at Sacraficio mountain shows bornite in brown garnet, the ore carrying silver values. The San Martin and Verde mines, a few leagues from the last, show similar deposits with shoots of rich silver ores, largely gray copper.

The mine Tepezala, at the place of that name in Aguascalientes, has silicious chalcopyrite ores. The Panuco deposits are pegmatite dikes carrying chalcopyrite.

The Dolores y Annexas, at Matahuela, San Luis Potosi, embracing the Dolores, Trinidad and Azul, are contact deposits between limestones and porphyries, the copper occurring as sulphides in a garnet gangue.

Jalisco

The Las Moras property, situated 8 miles from Ameca, resembles a contact deposit. The deposit is an immense crush zone traversing the foot-hills of a range of porphyry peaks. The mineralized zone is 300 ft. wide, traced for 2000 ft. in length. The ore is a breccia of light-colored altered, often garnetiferous, limestone fragments cemented by black calcite and chalcopyrite. The ore is low grade, averaging about 2 per cent. Chutes and stringers of higher grade ore also occur. The deposit appears to be a crushed and mineralized contact zone.

Oaxaca

Copper veins are worked near Ocotlan and near Ejutla, south of Oaxaca city. The ores consist of chalcopyrite with pyrite and quartz in well-defined fissure veins, cutting bedded andesite tuffs. The Ocotes mine at Ejutla produces about 400 tons of ore a month that averages 8 per cent copper. It is owned by the Teziutlan company.

Puebla

The Teziutlan ores occur in bedded deposits that are irregular branching replacements of beds of limey Cambrian slates. The rocks are much metamorphosed and have a dip of about 20 deg. There are no recent igneous rocks near by, but microscopic study shows that some of the slates are old sheared diorites. The ores are a mixture of copper, lead, and zinc sulphides.

[1] W. L. Austin, *Transactions* American Institute of Mining Engineers, vol. xxxiii, 1903, p. 1070.

XVII

COPPER MINES OF THE UNITED STATES

THE copper mines of the United States are by far the most important producers of the world, both collectively and individually. The bulk of the production is furnished by Montana, Michigan, and Arizona, coming from a single district in Montana, one in Michigan, and four in Arizona. The total number of producing localities is comparatively small (Fig. 2), and although there are often many mines in a district, the deposits of each group show such strong family resemblances that a general description answers for all the deposits of that district. At most of the copper areas there are a few large companies controlling many mines, commonly known collectively by the name of the company, as, for example, the Calumet and Hecla of Michigan, and Anaconda of Montana, each of which operates a number of mines on various veins. Individual mine names can, therefore, be disregarded in many cases.

The copper districts of the various states are described alphabetically, and not in their relative importance as producers. The Appalachian states are grouped together and the deposits described under that title.

ALASKA

The copper mines of Alaska promise a large production in the near future. The deposits near tidewater are already producing, and as the Copper River railroad lines will soon open up the cupriferous belt of the interior, the rich deposits of that section may soon enter the ranks of producing mines.

"In 1905 there were two copper-producing districts, Ketchikan and Prince William Sound, and in three more, the Chitina (Copper River basin), White-Tanana, and Kenai districts, considerable prospecting was done. Copper has also been found in other parts of southeastern Alaska and reported from a field lying immediately west of Cook Inlet. The deposits of Prince of Wales Island and of Prince William

Sound have shown rapid development, as compared with that of the inland districts, due to their proximity to tidewater, open to navigation throughout the year. Two smelters have been completed on Prince of Wales Island, but the bulk of the Alaska ores is still shipped to Tacoma.

"In the Chitina district prospecting is steadily progressing on the copper properties lying on the southern slope of the Wrangell Mountains.

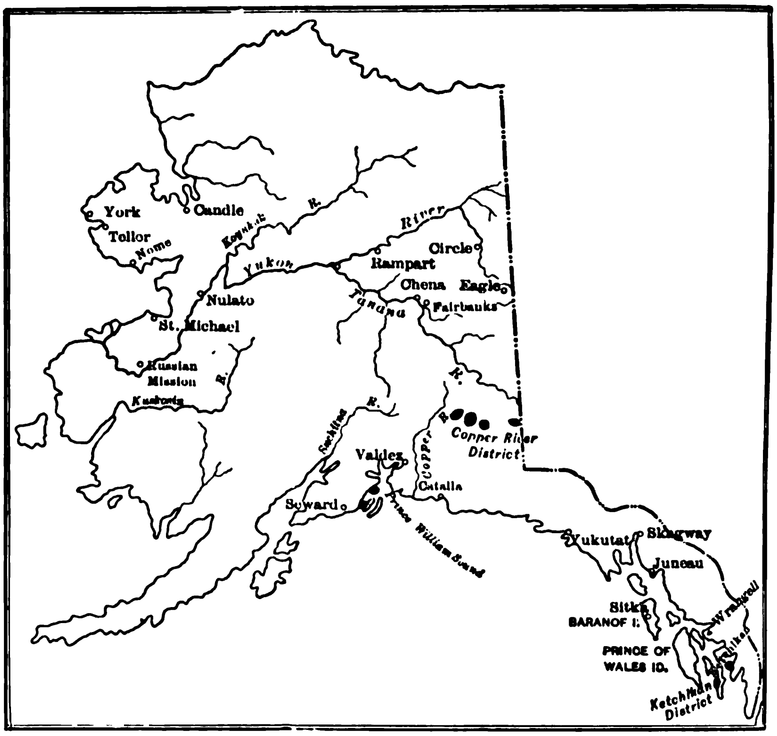


FIG. 102. — INDEX MAP SHOWING LOCATION OF COPPER MINES OF ALASKA

tains. At present this field is reached only after a 200-mile journey over a rough trail. Freight charges to the district are as high as a dollar a pound in summer and 15 to 20 cents a pound in winter. In spite of this excessive cost, considerable development work has been done in the district. The ores found in place are chiefly sulphide, for the native copper, occurring in the gravels near the east end of the field, has not been traced to its bed-rock source. The results of the prospecting of the last two years indicate a greater persistency at depth than was expected from the surface croppings. At the east end of the field a vein has been followed to a depth of about a hundred feet, and a lode near the west end of the field has been tested by diamond drilling to a depth of about 50 ft. The reported results of this prospecting indicate a permanence of the orebodies which augurs well for the development of an important copper district. Further operations must await the construction of a railway from the coast.

"A second, less-known copper belt lies north of the Wrangell Mountains, stretching westward from the international boundary, at the head of White river, to the headwater basins of Tanana river. These orebodies are closely associated with greenstones and limestones, but their form of occurrence is less well known in the case of the southern field. The reports of the prospecting of the past year warrant a further investigation of this belt. The permanent development of this field can be accomplished only with the aid of railway facilities, but the fact that water transportation is available within 50 miles of any point in the district is of the greatest possible importance, and this was demonstrated last year by Mr. Henry Bratanober, who took a small steamer up the Tanana to the mouth of the Nabesna.

"Mention should be made of the occurrence of lodes carrying copper sulphide in the Kenai Peninsula. Little is known of the character of these deposits, but they appear to lie in a southwesterly extension of the belt of metamorphic rocks which carry copper in the Prince William Sound region. Work on these deposits has been stimulated by the construction of the Alaska Central Railway."[1]

Prince of Wales Island, Southern Alaska. — The copper deposits of Prince of Wales Island, in the Ketchikan district, are at present the most important producers of Alaska. The chief mines are working contact deposits in garnetized limestones, adjacent to intrusive bodies of quartz diorite or of greenstone. The principal mines are either on the Kasaan Peninsula, on the east side of the island on Cleveland Peninsula, or at Copper Mountain, on the west side of the island.

The New York Smelting and Refining Company is operating mines and a smelter near Hadley, and the Brown Alaska Copper Company and Coppermount-Sulzer companies at Copper Mountain are developing their mines on the west side of the island.

[1] A. H. Brooks, "Mineral Resources of Alaska," *Bulletin* 284 United States Geological Survey, 1906, p. 3.

Hadley is on the northeast side of the Kasaan Peninsula. The country rock is greenstone, with intervening bands of contorted marble with interbedded bands of magnetite rich in chalcopyrite. These rocks

FIG. 103.—GEOLOGICAL SKETCH MAP OF COPPER MOUNTAIN REGION, ALASKA

and the ore deposits are cut by dikes of felsite and basic igneous rocks. The beds strike north and south and dip west. The ore, consisting of a close mixture of chalcopyrite and magnetite, is found in seven or more irregular lenses, varying from 20 to 40 ft. in thickness, and 100 to 150 ft. in horizontal extent. This ore carries $3\frac{1}{2}$ to $4\frac{1}{2}$ per cent copper, and $1 to $2 per ton in gold. Similar deposits occur on the southwest side of the peninsula.

The Coppermount-Sulzer properties are on the south side of Hetta Inlet, on the southwest coast of the island. The ore consists of chalcopyrite accompanying pyrrhotite, pyrite, and magnetite, with a gangue of quartz, garnet, epidote, etc., and is a contact deposit in an altered limestone, adjacent to granite belts or greenstone diabase dikes.

The deposits of the Alaska Copper Company are on the south side of Copper Mountain, on the western slope of the island. They are found about a mile from tidewater, and outcrop 3300 ft. above it. The ores are of typical contact metamorphic character, and contain the copper as chalcopyrite. The property is extensively developed and has a smelting plant.

The Jumbo group, on the north side of Copper Mountain, is of similar character, diabase and limestone being the country rocks. These deposits, and the Green Monster claims 6 miles east, belong to the Alaska Industrial Company, the claims being located on a granite-limestone contact.[1]

The *Prince William Sound* or Valdez region contains two producing mines and many promising copper deposits. The accompanying index map shows their distribution. In general the ores are sulphides, chiefly chalcopyrite with associated pyrrhotite and pyrite in a gangue of quartz and country rock. These ores occur in lenticular orebodies in shear zones whose direction coincides with that of the contact between greenstone and layers of slate or graywacke, or to the foliation of the rocks. The region as a whole consists of sedimentary rocks intruded by granitic masses, aplite dikes, and basic dikes, and with basic lava flows, now altered, sometimes schistose, and in part resembling the Lake Superior traps. These rocks are best designated as greenstones, and are the most abundant and characteristic rock of the district. The sedimentary rocks are black or dark gray slates, graywackes, and rather rare beds of conglomerates of black limestone. All these rocks become schistose near granitic masses.

The Gladhaugh or Ellamar mine is located at the town of Ellamar. The orebody is a lens, whose greatest thickness is 80 ft. and whose horizontal length is 190 ft. on the 200-foot level. The ore varies from

[1] F. E. and C. W. Wright, in "Mineral Resources of Alaska in 1904," *Bulletin* 284, United States Geological Survey, p. 46.

solid sulphides to impregnated country rock. It is inclosed in a crushed and soft black slate with some layers of graywacke and black limestone. As shipped it averages 7.4 per cent copper, an ounce in silver, and a trace of gold.

At Copper Mountain, four miles southeast of Ellamar, there are a number of all but undeveloped deposits in shear zones in greenstone and slates. The deposits are on Galena bay, Boulder bay, and Landlocked bay. The largest known deposit of the Prince William Sound region is the Bonanza mine on Latouche Island. The deposits outcrop to a bold cliff facing west that is 50 ft. to 200 ft. high, 120 ft. thick, and over 200 ft. long. The ore consists of chalcopyrite with associated pyrrhotite.

This ore occurs in a shear or brecciated zone in graywacke and slate. The rock of the ore zone is very fine-grained, greenish gray, and flinty, and evidently a silicified replaced slate. It is cut by many films and veinlets of quartz containing copper.

About 1000 tons a month were shipped in 1906. The ore carries an average of 40 per cent silica, 17 per cent iron, 6 per cent alumina, and 14 per cent sulphur, with 8 per cent copper and an ounce of silver per ton. There are a number of other large and promising deposits on Latouche Island, notably the Blackbird and Blue Fox claims.

Glacier Island contains deposits at the east end. The island is composed of greenstones (Orca series), cut by shear zones, and traversed by irregular copper-bearing quartz stringers and veins.

Knight Island contains deposits on the eastern shore, and at Mummy bay on the southwest shore. At the first locality chalcopyrite with quartz occurs in a shear zone in greenstone and graywacke. At Mummy bay there are two claims showing narrow bodies of sulphide ore in crushed greenstone. A lens of sulphide ore also occurs at Drier bay on the west coast of the island.[1]

Copper River Field. - The third great copper field of Alaska embraces the mountains about the headwaters of the Copper and Tanana rivers, in the Mount Wrangell district. The Copper River field lies 100 miles from the coast, in the interior basin of the Chitina river.[2]

In the interior region of the Copper and Tanana rivers, the Nicolai

[1] Ulysses S. Grant, *Bulletin* 284, United States Geological Survey, 1906, pp. 78-87.

[2] For routes to this region and account of the geology, see "Geology of Central Copper River Region," *Professional Paper No.* 41, United States Geological Survey, p. 61, Washington, 1905.

greenstone forms a copper-bearing mass of enormous extent. This remarkable body of igneous rock, extending along the Alaskan mountains for nearly 300 miles, is lifted and upturned with the Permian (Chitina) limestone, which lies about its borders. It does not break through the limestone or send out dikes or arms into it. This great mass of rocks, which consists partly of intrusive masses, but mainly of amyg-

FIG. 104.—SKETCH MAP OF COPPER LOCATIONS OF PRINCE WILLIAM SOUND, ALASKA

daloidal surface lavas, is cupriferous over a very extensive area, and in places, as at Bonanza Creek (Copper River), carries disseminated bornite and veins of glance in what appears to be fresh rock, together with associated magnetite and pyrrhotite.

According to Schrader,[1] the Nicolai greenstone consists of volcanic

[1] For a description of the Nicolai greenstone, see United States Geological Survey report by Schrader and Spencer, on Copper River District, 1901.

flows varying laterally and vertically, and constituting a unit com with adjacent rocks. It is composed of green to red feldspar, augite, lesser amounts of chlorite, a little serpentine, and some acc magnetite. The rocks are mainly altered basalts. Locally the tain metallic copper, which is secondary. Both the greenstone ar adjacent sedimentaries are fractured and the fissures become The copper occurs in the fissures in the greenstones or in the mentaries only near the contact with the greenstone.

The copper deposits of this region are associated with the N greenstone, either as "bunch" deposits of native copper and oxi shear zones and disseminations, or as ore shoots of glance and b in veins in the greenstone at the limestone contact. Accordi Schrader, the tabular or vein deposits include the Bonanza, Ni and Elliott creek mines, in all of which bornite is the usual ore, tl glance prevails at the first-named mine, and chalcopyrite is com These sulphides carry gold and silver values. In general, the cc between the Chitina limestone and the Nicolai greenstone is the bearing horizon. The outcrop of this contact throughout the di is shown in Fig. 105.

The Bonanza mine is located 1500 ft. above timber line, on the slope of a ridge 4500 ft. high, 6 miles above the foot of Kennicut gl The ore occurs in a fissure vein 2 to 7 ft. wide, cutting both limeston greenstone at right angles to the contact, and exposed for a hig 150 ft. along the slope, and for 400 ft. horizontally. The vein is t able across the cliffs and for half a mile beyond the mine as a b fissure filled by limestone fragments cemented by calcite and devo copper, but it is barren except in the greenstone immediately belo contact. A 40-ft. shaft sunk on the ore shows the deposit to be lir to that depth, and the orebody is probably a surface enrichment, similar to the ore shoots of the Elliott creek mines. The vein north 40 deg. east. The ore is solid glance and bornite, devoid of gar and carrying 70½ per cent copper, with 14 oz. silver per ton.[1] The Independent, northeast of the Bonanza, has a 6 to 8 in. wide fi vein running north 20 deg. east through the greenstone and car bornite, with scanty gangue of quartz and calcite.

The Nicolai mine lies 8 miles east of the Bonanza, at 1000 ft. a timber line. The vein occurs in greenstone about 50 ft. below the ba the limestone cliffs. The fissure runs north 50 deg. east, dips 65

[1] Schrader and Spencer, "Geology and Mineral Resources of a Part of the C River District," United States Geological Survey, 1901, pp. 85, 86.

FIG 105 —CHITINA COPPER REGION, ALASKA

southeast, and shows faulting. Two parallel low-grade fissure veins occur near by. The vein is 8 to 12 ft. wide, with a greenstone rib or "horse" 3 to 4 ft. wide in the middle. The ore is nearly pure bornite, with scanty quartz and a little chalcopyrite at times.

The Elliott creek [1] mines are also located in the greenstone contact. The ore occurs in bunches or shoots, limited to 25 ft. horizontally and to a few yards in depth. There is no definite vein, but in places a belt of slightly crushed greenstone. The orebodies have no sharp limits, but their greatest extent is parallel to the contact and the false bedding of the amygdaloidal greenstone. The recognizable fissures run north 10 deg. east, dip 70 deg. west; north 12 deg. east, dip 45 deg. west.

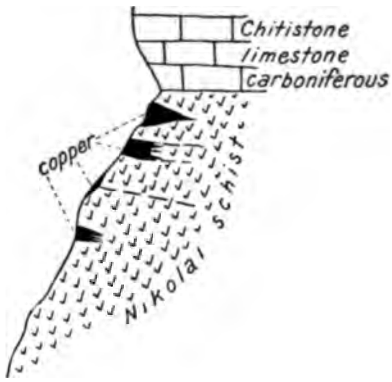


FIG. 106.—OCCURRENCE OF LENSES OF HIGH-GRADE ORE, CHITINA FIELD, COPPER RIVER, ALASKA

Other deposits of similar nature occur at the head waters of the Chitina, on the Nizina, and across the range on the head waters of White river. Copper nuggets are abundant in the gravels of the Chitina placer field.

The Kotsina basin contains numerous deposits showing native copper near the base of the greenstone, in compact quartz veins and filling amygdaloid cavities in the greenstone, associated with epidote. Bornite and chalcopyrite also occur as cores to small irregular orebodies, in which ore shades off into country rock. Deposits are also known on Kluvesna and Copper creeks.[2]

[1] From information furnished by H. V. Winchell.
[2] Schrader and Spencer, *loc. cit.*, p. 85.

Appalachian States

The Appalachian States contain copper ores at various places scattered from Maine southward to Alabama. They occur both in the Blue Ridge mountains and the Piedmont plain to the east, and include a variety of types. There are few producing properties, though many attempts and much money have been expended, especially on the delusively attractive ores found in the Blue Ridge region of Pennsylvania and Virginia. The deposits are of six varieties: (1) Pyrite masses in schistose rocks, now mostly mined only for their sulphur content, but including the veins of the Ducktown type; (2) Virgilina type; (3) Gold Hill type; (4) Seminole type; (5) Blue Ridge or Catoctin type; (6) New Jersey type. The different character of the deposits is perhaps unduly emphasized by calling the extreme examples types, and this designation is not intended to carry the same weight as when used in the chapter on "Classification."

New England. — Four New England States contain pyrite deposits that carry small amounts of copper. At Milan, in Coos county, N.H., lenticular masses of pyrite lie interbedded with chloritic schists, the overlapping lenses averaging about 8 ft. thick and 600 ft. long.[1] The upper part of all the pyrite deposits of the Allegheny region contain portions rich enough in chalcopyrite to warrant hand picking.

In Massachusetts a deposit of this type has been worked at the Davis mine in Franklin county, for 25 years. An impregnated band of the "Savoy" schist, a "fahlband" some 15 to 20 ft. wide and 700 ft. long, exists at a locality 2 miles west of the Davis mine, and shows a chalcopyrite streak on the north wall. At Windsor Bush, 11 miles from Davis, in Hampshire county, a similar deposit exists.

Other pyrite deposits are said to occur at Simsbury, Conn. At Bristol, in that State, copper ores occur in a fault or contact band between a gray gneiss hanging and a hornblendic schist foot, these rocks forming a hill rising above the Triassic sandstones. The property was worked from 1847 to 1854, yielding $200,000 worth of ore carrying bornite, chalcopyrite, and glance. Similar ores, associated with amphibolite and limestone, occur at Carmel Center, near New Haven, and at Bowers Hill.

The copper deposits of Vermont were important producers for many years. They occur in Orange county, near the Connecticut river, in the central part of the State. The orebodies are of the familiar pyrite

[1] "Mineral Resources," United States Geological Survey, 1884.

FIG. 107. — ORE-SCHIST, ELY, VERMONT

class, but more like the Norwegian than the Huelva or Ducktown deposits. The rocks are contorted and crinkled metamorphic crystalline schists, which form a broad anticlinal arch whose oldest and lowest beds contain calcite, and are called calcareous mica schists by the State geological survey. These rocks grade into sericite schists carrying limestone lenses, the schist series forming the core of the arch and surrounded by Paleozoic sediments. Dikes of granite and pegmatite, the latter with chalcopyrite, pyrite, and tourmaline, occur. According to Smyth[1] the rocks are altered sediments with northwest strike and steep northeast dip, the bedding all but obliterated by a pronounced northwest and southeast foliation, a schistose structure oblique to the bedding, with flat 15 to 35 deg. eastward dip. These broad relations are disguised near the orebodies by minor cross folding, due to a buckling of the main fold.

The known orebodies comprise those of the Union mine at Corinth, the Ely at Copperfield, and the Elizabeth at South Strafford. The ores are much alike at all the deposits, and consist of pyrrhotite and chalcopyrite, with quartz and tourmaline. The Ely orebody has a rudely elliptical cross section, is some 20 to 30 ft. thick, 50 to 150 ft. wide, and is worked on the dip for 3600 ft. The ore is quartzose, and for the most part free from schist, but at the borders the ore shoot frays out into schist and it is also schistose where an underlying lens splits off from the upper, main mass. According to Smyth the orebody lies along the axis of one of the lesser or cross folds, a place where the beds have slipped and parted, giving rise to connected open spaces in the saddles, and the spaces were filled by sulphides, with probable accompanying replacement of crushed schist. These saddles became channels for mineral-bearing solutions.

The Elizabeth deposit at South Strafford is a pod-like mass (shown diagrammatically in Fig. 108) found in a fault fissure that follows the contact of a narrow dike of biotite granite and the mica schist, the ore replacing both granite and schist.

In general, it may be said that the orebodies of this region have been formed since the folding of the rocks and are not the result of regional metamorphism. Ore deposition probably followed the intrusion of the granite batholite exposed at Barre and elsewhere, and probably underlying the whole region, and the folding at the Ely and faulting at the Elizabeth possibly result from settling. That the mineralization was pneumatolytic in character, and due to emanations from the granite

[1] *Engineering and Mining Journal*, April 28, 1904, p. 677.

magma, is shown by the tourmalinization and occurrence of chalcopy in the pegmatites of the district.

New Jersey contains numerous copper deposits associated v diabasic intrusions in Triassic Red Beds. These deposits are simila character, but vary in copper content. They were worked in Coloi and Revolutionary days, the nodules of oxidized ore in the weathe zone being easily mined and reduced. The largest and most interest example outcrops along the lower slope of Watchung (or Orange) mo tain, near Somerville and Bound Brook. The ore bed lies directly neath the main trap sheet of the mountain, a mass of basalt (a rock of called dolerite and varying to a diabase in texture) of extrusive ori contemporaneous with and buried beneath Triassic sediments. T trap sheet is about 500 ft. thick and with the shales beneath it tilted, d ping at 18 deg. to the northward.

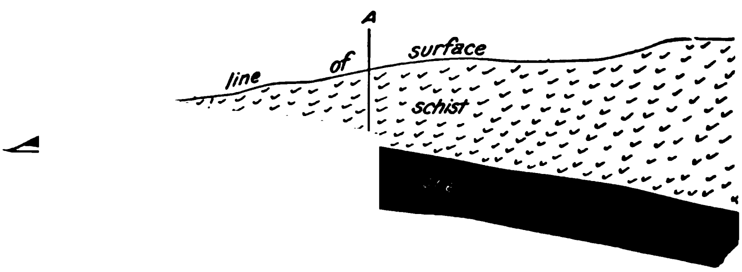


FIG. 108.—CROSS-SECTION OF OREBODY, ELIZABETH MINE, SOUTH STR FORD, VERMONT

The deposit is not a vein, but a bed of dense and firm purple ro lying against the trap and underlain by dark red shale. A study thin sections under the microscope shows the ore-bearing rock to indurated volcanic tuff. The copper occurs in an oxidized form to depth about 600 ft. on the dip. Below this point the metal occu native, or with a very little glance, and is found in disseminated grai or bunches in whitish or greenish patches, due to a bleaching of t inclosing rock. The ore bed varies from 15 in. to 3 ft. in thickness, a the reports of sampling by various well-known engineers shows it carry 2 per cent copper. The ore bed is traceable by recent or o workings for fully 5 miles along the mountain front. At the Americ mine the inclined shaft is 2360 ft. deep.

At many localities the sandstones overlying the trap rocks carry copp ores in the joint planes and in places between the grains, as is seen

Arlington, N.J. Impregnations and staining of shale are also common adjacent to nearly all the intrusive bodies of trap of the State. The Griggstown deposit occurs in a shale altered to spilosite (a spotted hornfels), as a result of marked contact metamorphism, and overlying a thick diabase sheet. The ore contains chalcopyrite, magnetite, and hematite, but the orebody is small and low grade. Most of the New Jersey deposits show, however, clear evidences of their derivation from the trap as a result of hydrometamorphism, an alteration due to ordinary atmospheric waters, the adjacent shales absorbing and retaining the copper by the so-called absorption process.[1]

At Pahaquarry mountain, near the Delaware Water Gap, the north flank of the mountain is composed of steeply tilted red shales and sandstones of the Medina period. A part of this series consists of beds of gray sandstone, interbedded with red shales, and impregnated with copper glance. Over 200 ft. in thickness of this sandstone carries over 1 per cent and often 2 per cent of copper as a cement between the grains. No igneous rocks are known near by.

Pennsylvania contains no producing copper mines. The South Mountain region has copper ores in basic igneous epidotic schists, and the failure to recognize the nature of the deposits has led to great loss and disappointment. The belt is some 13 miles long, extending 4 miles into Maryland. The deposits are of the Blue Ridge or Catoctin type. The ores consist of cuprite and native copper, with secondary carbonates, in cracks and quartz-calcite veinlets, either in a basalt altered to greenstone or at the contact with rhyolite changed to slate, etc. The replacement of feldspar by chlorite and epidote, and their replacement by copper, is characteristic.[2]

Copper ores occur rarely and in small quantity in the Catskill shales underlying the Coal Measure rocks of northern Pennsylvania.

Copper ores also occur on the margin of the magnetite deposits of Cornwall,[3] the Gap mine in Lancashire county, and at the Perkiomen mine in sandstone near amphibole gneiss.

Maryland contains several old and now idle copper mines, situated in three copper belts. The first extends from New London, in Frederick county, to Union Bridge; the second from Finksburg through Carroll county to Sykesville; the third is the Bare Hill region, near Baltimore. The first belt contains deposits of bornite, chalcopyrite, and glance in

[1] E. C. Sullivan, *Economic Geology*, vol. i, no. 1, 1905.
[2] Florence Bascom, *Bulletin* 136, United States Geological Survey, pp. 26, 27.
[3] Kemp, "Ore Deposits of the United States," p. 149 (1st edition).

pure and impure marbles folded in shallow troughs and inclosed in micaceous schists that are, in part at least, disguised volcanics. The Liberty and other old mines are in this belt. Numerous deposits in the vicinity of Union Bridge await development. The limestones form narrow, sharply folded, but long troughs, with associated belts of greenstone. The copper is confined to the limestone or its contact.

The second belt shows a fissure vein, traceable as a fault plane, mineralized at various points for a distance of 25 miles. The ore consists of chalcopyrite, with secondary products in a gangue of steatitic material, with siderite, actinolite, epidote, and quartz, with magnetite and rare cobalt minerals.[1]

The Bare Hill region, at Mount Washington, a few miles northwest of Baltimore, was for many years a small producer. The ore is chalcopyrite with bornite in a gangue of black amphibole schist. The 2 to 5 ft. vein is an interbanded layer of amphibolite in gray gneiss, near a serpentinized peridotite intrusion. The vein shows movement and crushing. It is now idle.

Virginia. — Copper ores occur in many counties of the State, and in many ways, though no profitable copper mines have thus far been developed outside of the Virgilina district. The upper portions of the pyrite deposits of Louisa county yielded copper ores in small amount, but were never of importance as copper producers. The great pyrrhotite vein or "gossan" lead of southwest Virginia furnished considerable quantities of secondary "black copper ore" in the early fifties, and in recent years the quartz veins of the Virgilina district have shipped considerable ore.

The Appalachian gold belt, extending along the upland plateau of Virginia and the Carolinas, Alabama and Georgia, contains numerous veins carrying copper as well as gold. These veins show a marked clustering about the margin of the great granite area of North Carolina, resembling in this association the Sierra Nevada copper belt, and the gold deposits about granitic borders in Montana. Though usually classed as gold veins, they, as a rule, develop refractory sulphide ores below the water level, composed of pyrite and chalcopyrite in a silicious gangue, either altered schist or massive quartz.

Veins exposed near Charlottesville, Dillwyn, and Keyesville show ore of somewhat more favorable texture, with some higher-grade material, but of undeveloped size and unknown value.

[1] "Geology of Baltimore and Vicinity." Guide Book for American Institute of Mining Engineers, 1888, p. 20.

The "Gossan Lead" of Floyd, Grayson, and Carroll counties is a vein traceable for some 11 miles. It is composed of pyrrhotite, with admixed quartz and schist, and carries patches and streaks of chalcopyrite. The vein fills a fault fracture between schistose or slaty rocks of probable Cambrian (Ocoee) age and a schistose metamorphosed diorite. The vein dips at 30 deg. east, and has been extensively worked for its limonite gossan. The copper content of the sulphide ore is too low — about 0.75 per cent — to work for this metal, but the vein is now mined on Chestnut Ridge, at the southwest end of the vein, and the ore treated at Pulaski for its sulphur content, so that the residue is available for copper.

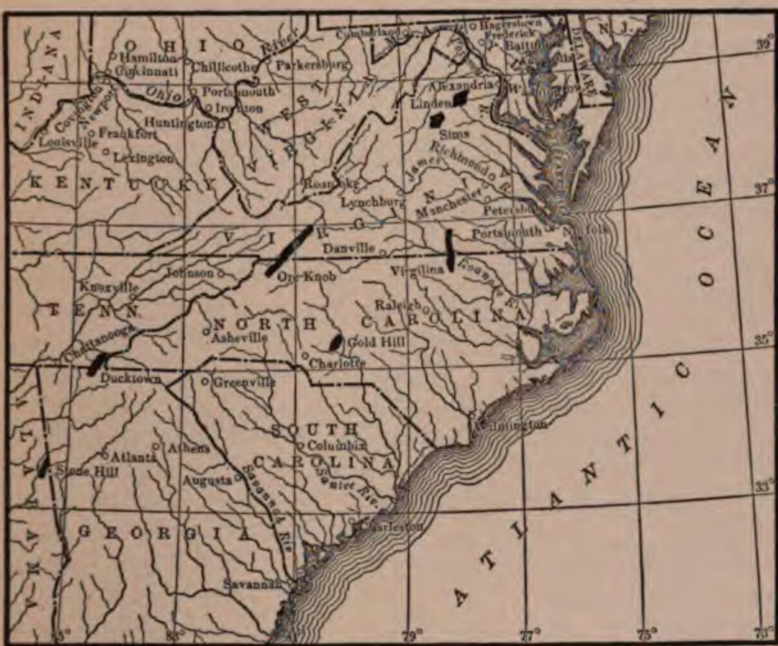


FIG. 109. — INDEX MAP OF THE APPALACHIAN REGION

The Blue Ridge deposits deserve mention only because they are extensively and persistently advertised as great copper deposits. The region is one of old — pre-Cambrian — basaltic lava flows, capped by sediments and intruded by granitic rocks. This complex has been folded and subjected to regional metamorphism. Local concentration of the minute copper contents of the basic rock has been effected by surface waters, with attendant gathering of the copper in cracks and "gash" veins, with associated epidote and quartz. The copper occurs mainly as native and red oxide, but small amounts of red and blue carbonate occur, and at some localities bornite and chalcopyrite. When unusually developed local shearing occurs, it has permitted the descent of surface waters, and the ores extend downward below the 20 or 30 ft. to which they are usually confined. Near Ida, Page county, copper minerals are found in such sheared rocks at a depth of 300 ft. Nowhere have these ores as yet been found in payable quantity. Though widely distributed and of seductive richness at the surface, the deposits have invariably proved unworkable upon development.

Copper ores occur in Triassic shales near Leesburg, Fairfax county, and in Orange county, but are not workable.

The *Virgilina* field differs materially from all the other copper-bearing districts of Virginia. The ores consist of glance and bornite in white massive quartz, forming lenticular shoots or masses varying from a few inches to hundreds of feet in length, and up to 20 ft. in thickness. These ore shoots lie in well-defined fissure veins that cut finely schistose rocks, formed of andesite and other volcanic rocks. Their strike usually corresponds nearly to the foliation of the inclosing rocks, but cross veins occur, spurs are common, and development shows that where the quartz gives out the vein continues as a well-defined fissure filled by friction breccia, composed of crushed and altered fragments of the country rock and fault clay.

The Virgilina copper belt extends in a general northeast and southwest direction through parts of Halifax county, Va., and Person and Granville counties, N.C. It is 150 miles from Norfolk, and 48 miles east of Danville, Va. The belt is 16 miles long, Virgilina being in the center. The veins occur in green, somewhat massive schists, which are disguised volcanics, mainly andesite. The foliation is east of north, and the dip east. The veins mostly run nearly north and south, cutting the schists at a low angle. Their dip is east 70 to 80 deg. The vein filling is quartz, with some calcite and slivers of schist. The copper occurs as bornite and chalcocite. There are several cross veins, notably the Holloway. The quartz is very hard, and the copper contents average 2 per cent.

The Durgy mine, owned by the Person Consolidated Copper Company, lies 7 miles south of Virgilina. The vein is well-defined and persistent even when not copper-bearing. It is opened to a depth of 340 ft. The main ore shoot is about 450 ft. long and averages 8 ft. across, and is persistent downward. A second shoot lies to the south.

The ore will average 2 per cent copper and 0.9 oz. silver, with 70 per cent excess SiO_2. The veins beyond the quartz ore shoots are filled by a friction breccia of schist fragments.

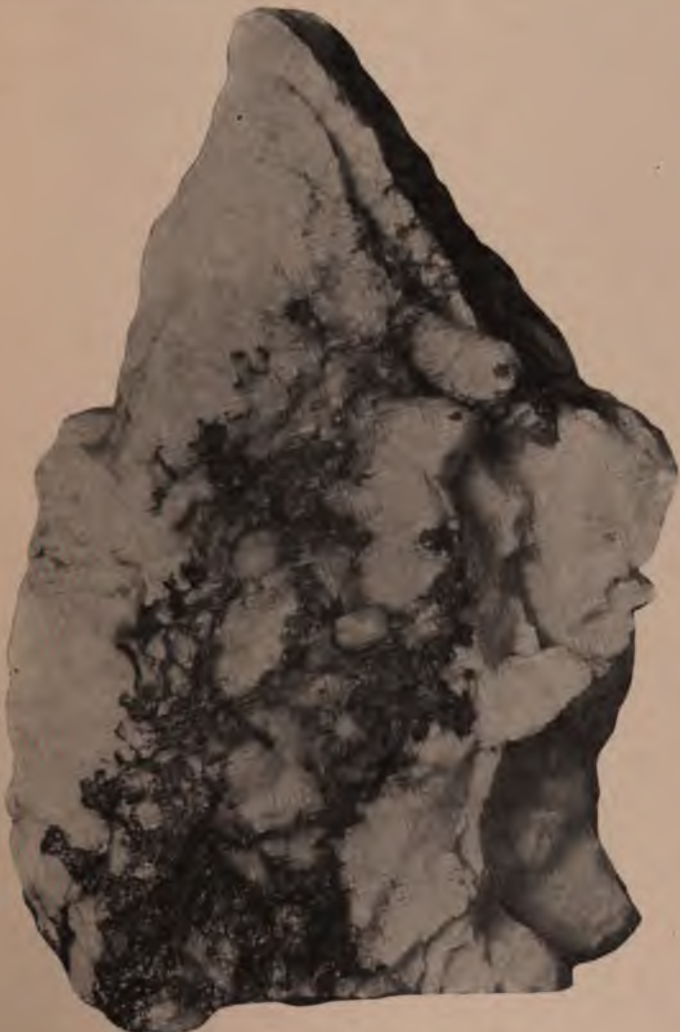


FIG. 110.—ORE FROM PERSON MINES, VIRGILINA, N.C.

The Blue Wing mine is 7¼ miles south of Virgilina, and belongs to the Boston and Carolina Copper Company. The vein is well-defined and persistent, crosses the schist and cuts through a diabase dike. The ore consists almost entirely of bornite, with quartz and calcite gangue. It is opened to a depth of 266 ft. and for 600 ft. in length, and shows an average width of 4 ft. The ore carries about the same amount of copper and silver as the Durgy.

The Holloway is a cross vein, showing a well-defined shoot of rich glance ore that was profitably worked for many years, and developed to a depth of 400 ft. The vein crosses the schists at a sharp angle.

The High Hill vein shows a very persistent outcrop of white quartz traceable for nearly 3 miles. It has been developed by 12 shafts, pits, and long levels. The vein varies from 6 in. to 15 ft. in width, the average being 4 ft. The vein carries some ore at every point seen. The main shaft is 339 ft. deep, with a level at 250 ft.

There are several other veins, developed by shafts 50 to 200 ft. deep, and showing similar but mostly smaller orebodies. The Wall vein is 4 ft. wide, and opened for 150 ft. in depth. The ore is similar to but lower grade than that of the High Hill. Selected ore shipped ran 9.7 per cent copper, and 1.6 oz. silver per ton, but the average is about 1¾ per cent. The Chappel, Tuck, Little John, and Seaboard veins are all similar.

North Carolina. — Besides the veins of the Virgilina field on the northern border, the State contains many gold-copper veins along the eastern and western borders of the granite area, particularly near Lexington, Salisbury, and Charlotte. The only productive mines are at Gold Hill near Salisbury. This district contains the Union Copper Company's mines and the Gold Hill mine. The former is 800 ft. deep and produced 480,000 lb. of metallic copper in 1905. The ore occurs in a well-defined shoot of dark gray quartz impregnated with chalcopyrite. This ore shoot is in a "schist vein" in rocks of probable igneous origin altered and presumably silicified to dense sugary quartz schists by emanations from granitic masses near by.

In the mountainous region southwest of Asheville there are a number of persistent veins, crossing the mountains, and marked by gossan outcrops. The Cullowee is the only one now worked. The Alice, Wolf creek, Brendle Knob, Poor Ridge, Savannah, Buck Knob, Way-ye-Hutta, and Hazel creek are all more or less developed. The Cullowee is a mineralized fracture plane following a basic band in the schist, carrying irregularly lenticular bunches of chalcopyrite ore, containing corundum and quartz and marked by a gossan outcrop.

There is one common feature in all the copper deposits of the North rolina mountains: the ores in the gray gneisses are later, and introced, but occur along or very near contacts with basic rocks, diabases, ., altered to hornblendic schists, and there is good evidence to show t the copper came from such rocks. Moreover, the basic schists nost invariably contain disseminated copper and iron pyrite.

According to Keith[1] all the Triassic diabases of the South contain pye, even in notably fresh and unaltered rocks, and it is easy to see that h pyrite, if cupriferous, could furnish the copper for chalcopyrite, segreted during this alteration to schist, possibly by molecular flow, or, more bably, by later currents which would circulate along foliation planes.

In the northwest corner of the State, in Ashe county, the Peachbottom n was formerly worked. It is a zone of gray quartz schist 3 to 4 ft. de, carrying small flakes of bornite and chalcopyrite intergrown with quartz. It is said to be traceable many miles, but is low grade and present remote from railway lines.

The Gap creek veins are quartz-filled fissures, showing comb quartz h bornite and chalcopyrite, carrying precious metal values. They re formerly worked, but have long been idle.

At Elk Knob, one of the highest peaks of the Appalachians (5555 ft. ove tide), a band of amphibolite traversing gray "Carolina" gneiss ries chalcopyrite disseminated through it and locally concentrated streaks. The only openings are high up near the summit, and show o 10 ft. of low-grade ore, whose hornblende gangue precludes success- concentration. The property is no longer worked.

The Ore Knob mine was for many years an important copper procer. It is a nearly vertical vein running with the foliation of the schist, t with steeper dip, which has been traced for 1½ miles. The ore conts of pyrrhotite, with some pyrite and chalcopyrite, resembling the cktown ore, but containing more silica. The mine was closed down en the price of copper fell below 10c. a pound, and is still idle. The ot of richer ore has been worked out to a depth of 200 ft. The in mass of the vein averages 8 ft. in width, and is said to contain per cent copper.[2]

The inclosing hard mica gneiss and schist runs north 57 deg. east, d dips at 40 to 45 deg. southeast. The rocks are crinkled and show all quartz nodules and streaks. According to Egleston, one wall is kensided, the other shows a transition of ore to rock. The vein

[1] Verbal communication.

[2] Weed "Types of Copper Deposits in the Southern United States," *Trans.* Am. Inst. n. Eng., vol. xxx, p. 449, 1900.

averages 10 ft. wide and is opened to 400 ft. in depth. It contained 20 to 30 per cent silica, and for some years copper was produced at a cost of 12½c. a pound. The Hunt and Douglas process was abandoned, owing to an increasing amount of lime in the deeper ores.

Georgia.—The Ducktown copper belt extends southward into Fannin county, Ga., where the Sallie Jane, Lot No. 20, and Mobile mines were once worked. The No. 20 mine, now reopened, is about 4 miles south of Isabella Ferry, lying between Pierceville and Frytown, Ga. The vein averages 20 ft. in width, and carries ore said to contain from 3 to 30 per cent copper. In the upper levels green carbonates are found, with the usual black ore near the water level, with gray and the so-called yellow ore below. The presence of feldspar in the ore is notable. The mine is 300 ft. deep (1905). The geological conditions are identical with those of Ducktown.

The Chestatee pyrite property, 6 miles from Dahlonega, yields cupriferous pyrite.[1] The ore carries 43.52 per cent sulphur, 39.70 per cent iron, 3 per cent copper, and 9.26 per cent silica. It consists of pyrite and chalcopyrite, forming a "bedded" vein conformable to the overlying quartz-mica schist, and underlain by hornblende schist. The outcrop is 2000 ft. long, and the thickness is from 20 to 30 ft. The copper percentage appears higher near the walls.

The Seminole mine,[2] in Lincoln county, 12 miles from Washington (Wilkes county), is a gold-copper mine with three well-defined veins, devoid of limonite gossan. Their course is north 43 deg. east, and the dip is west. The inclosing rocks are pyritized and silicified schists, which occur in a shear zone some 300 ft. wide, with normal mica schist on either side. This schist series carries foliated basic igneous rocks similar to those of Dahlonega, while dikes of later massive diabase cut all these schistose rocks and fault the orebodies. The ore is a dense dark gray quartz carrying pyrite and chalcopyrite, often showing a banded but not crusted structure. The ore occurs in shoots up to 8 ft. across, though averaging perhaps 3 ft. The mine is developed to the 185-ft. level. Between the veins the altered schists carry auriferous pyrite. The second class concentrates consist of chalcopyrite, 10.5 per cent; zinc-blende, 4.8 per cent; galena, 3.5 per cent; pyrite, 45 per cent; barite, 2.2 per cent; quartz, 17 per cent; and iron magnesian silicates, 16 per cent. This corresponds to about 3.6 per cent copper in the concentrates. The richer ore consists largely of copper sulphide, and

[1] E. C. Eckel, *Bulletin* 260, United States Geological Survey, 1905.
[2] W. H. Weed, *Bulletin* 260, United States Geological Survey 1905, p. 217 *et seq.*

carries $7 to $20 gold and some silver. The shipment for 1905 amounted to 163,478 lb. of ore, concentrates, and matte, carrying 19,394 lb. lead, 8841 lb. copper, 668.68 oz. silver, and 77.871 oz. gold. The ore shipped averaged 0.14 oz. gold per ton, 5.1 oz. silver per ton, 11 per cent lead, and 3.88 per cent copper, with 66.7 per cent silica, 4.6 per cent iron, 2.9 per cent zinc, and 8.9 per cent sulphur.

Alabama contains copper deposits of the Ducktown type, near Stone Hill, Cleburne county, in the so-called "copper lead" of Alabama, a belt of dark-colored hornblende schist. The property is idle and the workings are inaccessible. According to report it is 24 ft. thick, traceable for 1200 ft. on the surface, and the ore occurs in lenses of pyrrhotite with accessory copper pyrite. The inclosing rocks are a gray gneiss, with schist and hornblende gneiss, the Hillabee schist near by. The Smith mine, a mile northeast from Copper Hill, is similar in character and association.[1]

The Tallapoosa pyrite mine, 20 miles east of the city of that name, is said to show lenticular bodies of pyrite, with some chalcopyrite interbedded with the crystalline schists.

Arizona

Copper mining is Arizona's chief industry, the territory holding second place in the copper-producing states, and fourth in the list of the world's producing areas.

The production is almost entirely from the four widely distant districts, Bisbee in Cochise county, 6 miles north of the Mexican border, Morenci and Metcalf (Clifton district) in Graham county, Globe in Gila county, near the center of the territory, and Jerome in Yavapai county in the north-central portion. There are about 40 producing copper mines, situated in 11 out of the 13 counties of the territory.

The Bisbee District. — The copper output of this district is nearly half the total yielded by the territory. The chief producers are the Copper Queen, Calumet and Arizona, and Lake Superior and Pittsburg companies. The amount of gold and silver in the Bisbee ores is quite low, though the large tonnage of ore mined makes the total output of precious metals considerable. The district produced 593,000,000 lb. of copper up to May 1, 1906, all but 2,000,000 from the Copper Queen mine. The Copper Queen workings cover one-half square mile,

[1] William M. Brewer, *Proceedings* Alabama Industrial and Scientific Society, 1897, p. 13.

and the ore is developed to a depth of 1200 ft. The Calumet and Arizona is now (1906) 1200 ft. deep, the Lowell shaft 1200 ft., and various others 700 to 1200 ft. deep.[1]

FIG. 111.—INDEX MAP SHOWING LOCATION OF COPPER DISTRICTS, ARIZONA

The Bisbee district is in the central part of the Mule mountains, a few miles north of the Mexican line. The principal orebodies lie south of and within a mile of the town of Bisbee. They occur in Carboniferous

[1] F. L. Ransome, *Professional Paper No.* 21, United States Geological Survey, 1905. See also "Contributions to Economic Geology," *Bulletin* 203, United States Geological Survey, 1904, p. 152.

FIG. 112.—SACRAMENTO HILL FROM THE NORTH, BISBEE, ARIZONA

FIG. [illegible].—IRISH MAG AND SPRAY SHAFTS, FROM SACRAMENTO HILL limestone, on the southwest side of a great fault, and closely associated with a boss of granite porphyry, which lies across the fault planes in the eastern part of the area. The limestones form a shallow basin cut across the center by this fault. The ore occurs in roughly sheet-like masses more or less parallel to the bedding of the limestone and mostly within 1000 ft. of the fault or the granite porphyry intrusion. At the town the ores come to the surface and are worked downward for 400 ft., but the ore occurs at greater depth to the southeast of Bisbee, and in the Calumet and Arizona mine was first found at a depth of 800 ft., thus indicating that the ore occurs at increasing depths toward the center of the local basin formed by the beds, though not confined to any one horizon.

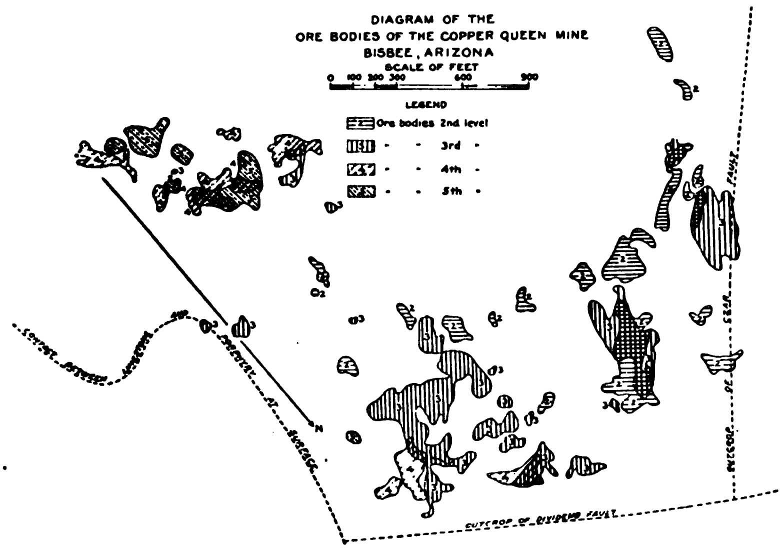


FIG. 114. – PLAN OF OREBODIES, BISBEE, ARIZONA

The contacts between the porphyry and limestone are irregular and jagged, vertically and horizontally. Frequently it is hard to recognize the contact underground, both rocks being silicified. No valuable orebodies have been found on the contacts. Ore stringers varying from mere films to several inches thick have been followed for hundreds of feet into valuable orebodies.

Thus far all the orebodies, save those in the extreme western workings of the Copper Queen, lie in the Carboniferous limestones. Though

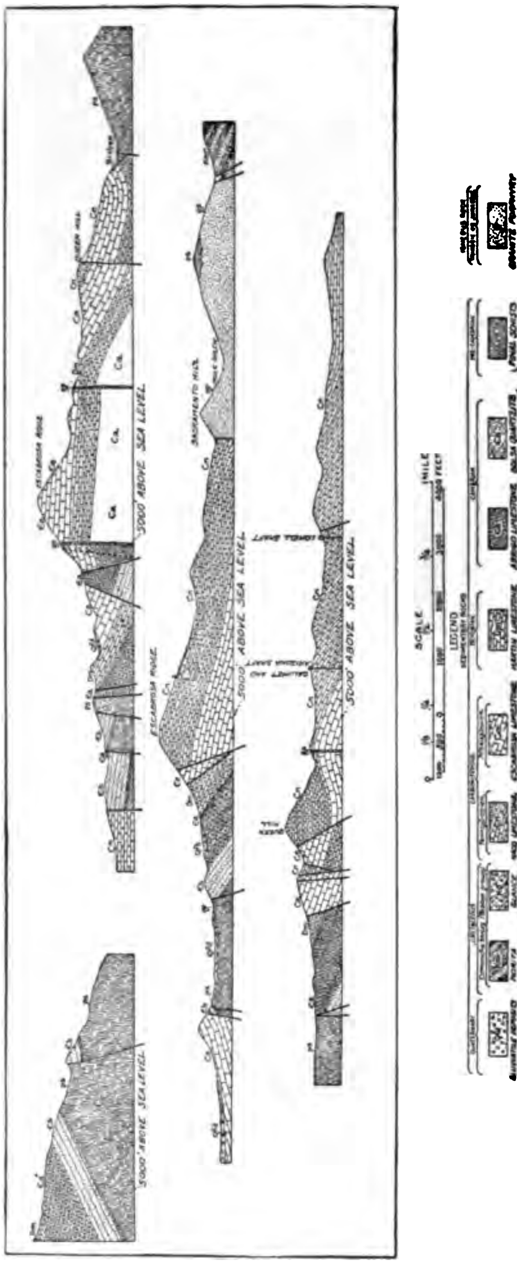


FIG. 115. – CROSS-SECTION, BISBEE DISTRICT, ARIZONA. (RANSOME)

these flat orebodies lie with the bedding of the limestone, their occurrence is dependent upon other structural features; large masses of low-grade, partly oxidized, pyrite ore occur along the contact between porphyry and limestone; other large orebodies turn down alongside porphyry dikes, and, in general, fissures in the limestone influence the distribution of the ore. There is an observed relation between permeability and good ore.

The extensive contact metamorphism, the association of ore and garnet, epidote and other "contact" minerals, and the close resemblance of the structural conditions to those prevailing at Morenci, seem to the writer to prove that the ore deposits have a similar genesis.

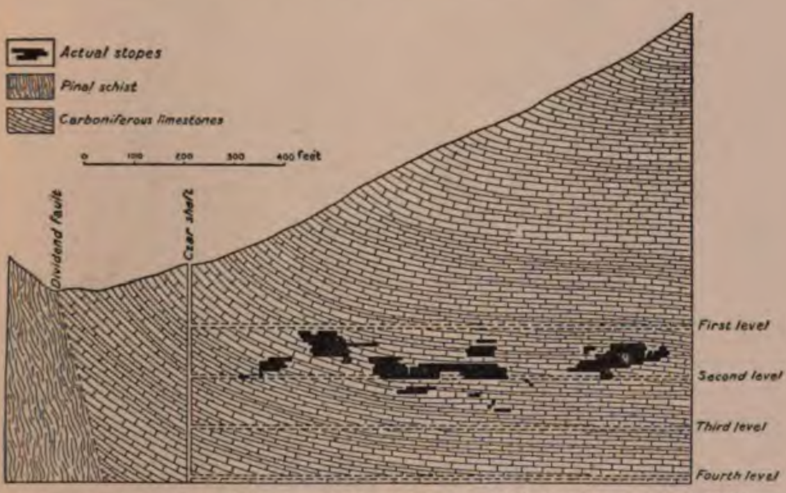


FIG. 116.—CROSS-SECTION OF CZAR SHAFT OF THE COPPER QUEEN MINE. (RANSOME)

The disseminated pyritic ore of the main porphyry mass of Sacramento Hill has not so far proved workable. The limestone near the surface has caves of irregular shape, one of them 300 ft. wide and 700 ft. long, and lined with malachite, and azurite, and stalactites of calcite. These "cave" ores, for which Bisbee was so long famous, are now exhausted. The ores now mined consist of pyrite, with variable amounts of chalcopyrite and glance.

The zone of oxidation is irregular, and sulphide ores are in places found but 50 ft. down, while oxide ores occur at depths of 1200 ft. or more. Masses of lean pyrite ore, solid and unfractured, occur

FIG. 117.—PLAN AND SECTIONS OF STOPES IN COPPER QUEEN MINE (RANSOME)

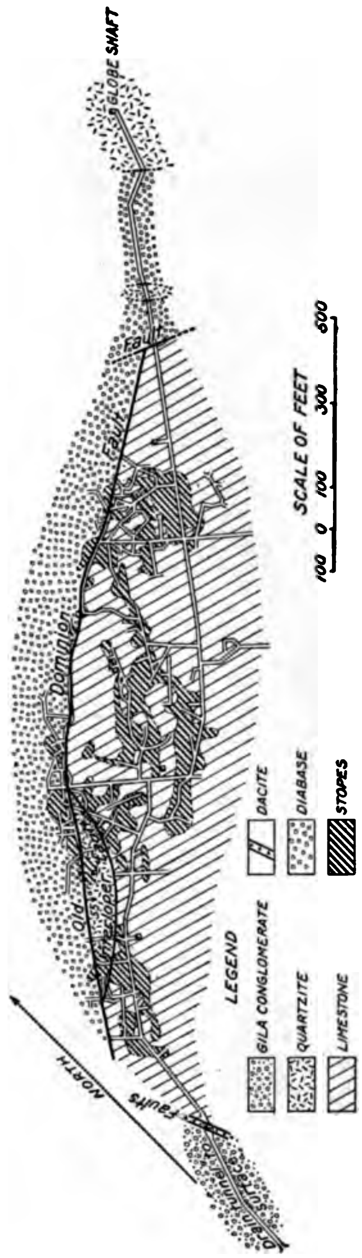


FIG. 118.—GEOLOGICAL PLAN OF THE SECOND LEVEL OF THE OLD DOMINION MINE. (AFTER RANSOME)

incased in rich glance ores, and represent the unaltered primary ore of the district, unattacked by percolating surface waters.

The Copper Queen is the oldest and largest mine. It has over 100 miles of levels, and hoists 1900 to 2000 tons of ore a day. There

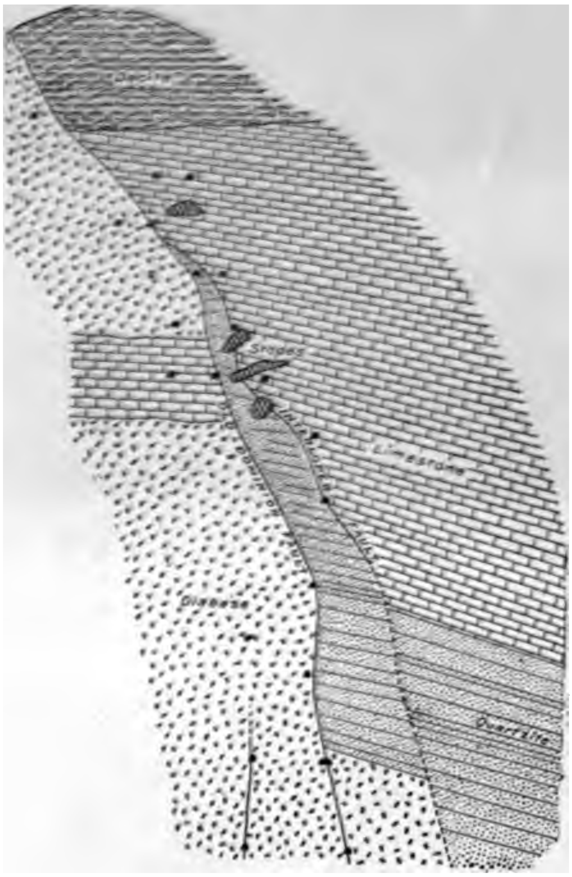


FIG. 119.—VERTICAL SECTION OF THE OLD DOMINION MINE, SHOWING THE OCCURRENCE OF FAULT IN THE DIABASE OF THE FOOTWALL. (RANSOME)

are five producing shafts, the Lowell, 1200 ft. deep, having 150 ft. of high-grade ore in the bottom.

Globe, Ariz., is an old and well-known copper camp whose production come ly from one mine, the Old Dominion. According to Ransome,[1] the chief production of the district is from orebodies lying in limestone, with lesser amounts from stringer lodes (pyrite ores of the Old Dominion and the Grey mines) and replacements of dacite tuff (Black Copper mine).

The important orebodies of the district are in limestone, and lie on the southeast side of the great displacement, separating the limestone from diabase, and known as the Old Dominion fault. The limestone series is 350 to 550 ft. thick, and rests on quartzite. The orebodies are rudely lenticular in shape and roughly parallel with the nearly horizontal bedding of the limestone. They occur at various horizons, but always alongside of or near the master fault. The largest orebody was 200 by 100 ft. wide, and 60 ft. thick. The ore of these great masses is all oxidized. Other orebodies consist of impregnations of shattered or permeable rock, quartzite or tuff, the ore passing into sulphides in depth. There is an evident association of the ores and faulting, and a genetic relation of ore and igneous rocks. The Old Dominion shaft is 1400 ft. deep. On this level an orebody 80 ft. wide has been cut in the main fault plane, that closely resembles the big fault-vein orebodies of Butte, Mont.

Christmas District. — The Saddle Mountain Mining Company owns mines located near the Gila river, close to Dudleyville, and near the San Carlos Indian Reserve. The deposits consist of oxidized ore occurring in altered limestones adjacent to porphyry intrusions, and of sulphide ore lying in limestone altered to garnet rocks, close to the porphyry contact. These orebodies are rich in magnetite, and carry approximately 8 per cent copper as chalcopyrite. The main shaft is (1906) 330 ft. deep. The ore smelted averages 3 per cent copper. The mine yielded in December, 1905, 394,318 lb. of copper, 90.98 oz. gold, and 3527 oz. silver.

The Ray copper properties are located in the central portion of an iron-stained and mineralized zone about a mile wide and possibly three miles long. This zone is sharply defined by its color and the nature of its rock from the gray foot slopes of the limestone crowned range to the east, and of the somber-colored hills to the west. It has a general northwest and southeast course and is cut across by Mineral creek, which shows exposures of this rock with frequent copper stains for a distance of about two miles. Copper canyon cuts a transverse section across the zone; and both this and the arroyo to the north

[1] Fred Leslie Ransome, "Geology of the Globe Copper District, Arizona," *Professional Paper No. 12*, United States Geological Survey, 1903.

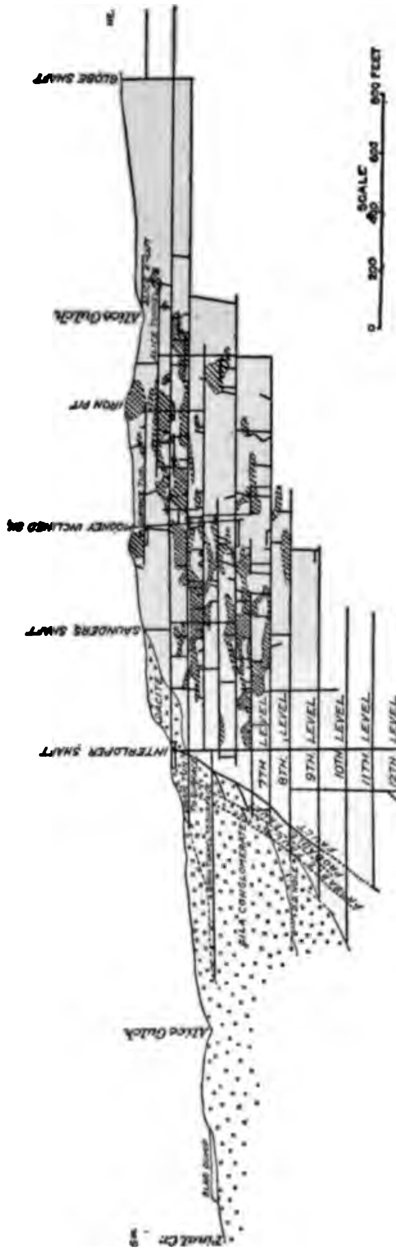


FIG. 120. — LONGITUDINAL SECTION, OLD DOMINION MINE. (RANSOME)

show immense masses of stream gravel cemented by copper silicate and carbonate.

This mineralized zone consists of a very thinly banded acid igneous rock, which in the hand specimen appears to be a flow rhyolite. This rock has been altered by hot-spring action very generally but not uniformly silicified, and shows bands in which the rock has been changed to almost pure quartz. At every place where openings have been made the rock shows small particles of pyrite coated by copper glance peppered through the mass, and with small veinlets one-sixteenth to one-quarter of an inch thick of pyrite and glance and with occasional bunches of larger size. The alteration of the rock has been accompanied with the formation of sericite, but the amount of the latter mineral does not appear to be so large as that in the ores of Morenci and Butte. The ore therefore consists of altered country rock with minute grains of glance and pyrite coated with glance. It will, therefore, probably change into a copper-bearing pyrite of too low a grade to work at a depth of a hundred or two feet below existing working. The ore developed at a depth of 250 ft. below the surface is similar in character and grade to that in the stopes above.

Tongues of granite appear to be intruded in the rhyolite, but they are mostly small. This rock appears highly altered, and so far as determinable does not cut out the ore. To the west of the ore zone a mass of basic diorite impregnated by copper pyrites is said to exist, but I did not see the rock in place.

The surface shows heavy iron gossan in a few places, but most of the surface is a rotted rhyolite stained by iron and showing green copper stains at very many places. The gravel cemented by copper in the bed of Copper gulch is being quarried and shipped.

The wide extent of the mineralization is only comparable with that of such districts as Cananea and Morenci. No limestones or other sedimentary rock were however observed near the ore zone.

The Clifton-Morenci district has for many years been one of the most important copper producers of Arizona, the total output to the end of 1903 being valued at nearly $50,000,000. The district is in the southeast part of the Territory in a mountainous region north of the Gila river. It is the terminus of a branch of the Southern Pacific railway running northwest from Lordsburg, N.M. The mines are at and about Morenci and Metcalf, the former being four miles and the latter six miles from Clifton.

The mines of the district yield relatively low-grade ores, having an average value for the year 1904 of but $7.84. The Arizona, Detroit, Shannon, Federal, and Standard companies are the principal properties. The copper deposits of this district have been investigated in detail by Lindgren.[1]

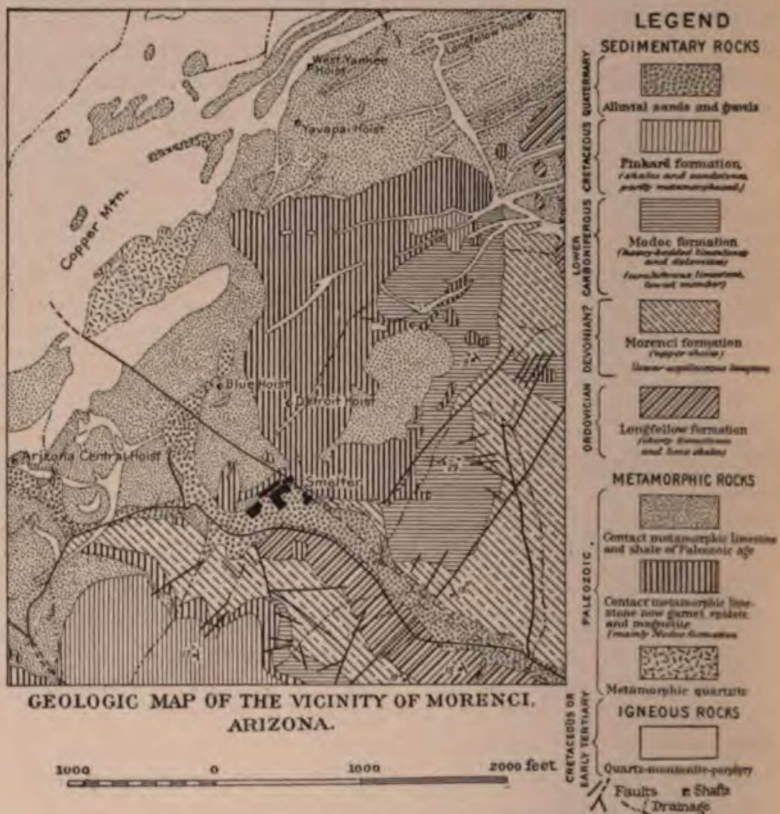


FIG. 121.—GEOLOGIC MAP OF MORENCI, ARIZONA

The geographical distribution of the copper deposits is practically coextensive with a great porphyry stock and its dike systems. The deposits occur either in the porphyry or close to its contact, or along dikes of porphyry in some other rock. Areas without intrusives are practically barren. This intimate connection between porphyry and

[1] *Professional Paper No.* 43, United States Geological Survey, 1905.

ore is as important here as it is at Cananea. The two important mining centers, Morenci and Metcalf, are situated on the main contact between a porphyry stock and Paleozoic limestones; elsewhere the porphyry adjoins granite or Cretaceous beds.

The ore deposits occur in part of an irregular mountain region, lacking defined ranges, and composed of a core of pre-Cambrian red granites, Cambrian quartzites, Paleozoic limestones, and a capping of Cretaceous beds. All these rocks are intruded by post-Cretaceous granitic porphyries. These rocks are surrounded and in part covered by volcanic lava flows, andesites, rhyolites, and basalts.

FIG. 122.—IDEAL CROSS-SECTION OF ORE DEPOSITS, MORENCI. (AFTER LINDGREN)

The ores consist of chalcocite and chalcopyrite with pyrite and the usual variety of oxidized ore minerals, with brochantite, a basic copper sulphate, unusually abundant. The deposits of payable copper ore occur in various widely differing forms, namely:[1]

Contact deposits in limestone and shale, not connected with fissure veins.

- Irregular bodies near contacts with porphyry mass or dikes.
- Tabular bodies near contacts of main stock or dikes, following bedding.
- Tabular bodies on contacts of porphyry dike.
- All the above deposits carry predominant oxidized ores.

Fissure veins and disseminations adjacent thereto.

- Normal veins in porphyry or contact zone about porphyry contacts. Includes central veins and altered mineralized porphyry adjacent to them, together forming a lode — carrying chalcocite as the important ore; some oxidized ore in upper levels.
- Normal veins following porphyry dikes in granite ores like last.
- Normal veins following diabase dikes; chalcocite ores.

Stockworks. — Irregular disseminations of chalcocite in porphyry, quartzite, and other rocks.

[1] W. Lindgren, "Genesis of the Copper Deposit of Clifton-Morenci." *Transactions* American Institute of Mining Engineers, vol. xxxv, p. 515.

U

The original ore of all these deposits is pyrite and chalcopyrite. The gangue of the ore varies with the class. In the contact ores it is often an altered limestone composed of garnet, epidotic diopsid, tremolite, etc. In the veins the scanty gangue is quartz. In the disseminated ores it is decomposed and bleached porphyry, retaining its original structure.

Extensive contact deposits occur where the Paleozoic limestone series comes in contact with the main body of porphyry at Morenci and at Metcalf. The deposits are the direct result of the action of the intruded igneous rock, the porphyry, upon the sedimentary rocks, and the metamorphism varies greatly in the different beds, and even in similar beds. The principal area at Morenci is 1000 to 1500 ft.

FIG. 123.—VERTICAL SECTION, RYERSON SHAFT, MORENCI. (LINDGREN)

wide and two miles long, and one formation, the Modoc limestone, a heavy bedded pure gray limestone 200 ft. thick, is altered to garnet and magnetite for 2000 ft. from the contact, though adjoining beds are unchanged. The contacts between igneous and sedimentary rocks are sharp, and the altered sediments hard and compact and not easily altered by weathering. The ores are characterized by magnetite, molybdenite, and scanty zinc-blende and galena, besides the copper minerals.

The fissure veins traverse both the porphyry and the contact zone. They carry pyrite with small amounts of chalcopyrite, zinc-blende, and molybdenite. These unoxidized ores are low-grade and usually unpayable. The filling is massive, granular, or rarely crustified, and shows but little quartz. These veins are accompanied however by the great bodies of disseminated ore which now form the mainstay of the district. This ore occurs in very wide zones adjacent to the veins. In these zones the porphyry is altered to a soft whitish mass composed largely of sericite quartz and pyrite — a rock conveniently designated as pyritized porphyry, and resulting not from hydrothermal alteration, but from solutions emanating from the porphyry mass itself.

The veins are marked by barren silicious outcrops, but the great masses of disseminated ore have no outward sign of their presence below.

The great bodies of oxidized ore of the Longfellow, Detroit, Copper Mountain, Montezuma, Manganese Blue, and Shannon mines are now nearly exhausted. They occurred in limestone and shale, were more or less tabular in shape, 1 to 30 ft. thick, and were rarely over 300 or 400 ft. in width and thickness. Several orebodies are sometimes superimposed within 300 ft. of the surface, as in the Detroit and Manganese Blue. That of the Longfellow mine is an inverted pyramid.

The West Yankee, Humboldt, and Copper Mountain mines are on a belt or lode of linked and branching fissures in porphyry a few hundred feet from the contact. A second parallel lode lies in metamorphic rock a few hundred feet from the first. The fissures are conjugate northwest or southeast, and have a steep dip. The deposits usually show a central vein 4 ft. or less in width, but sometimes 50 ft. wide, filled with nearly massive sulphides. The main ore supply comes however from the zone of altered "pyritized" porphyry on each side of the vein. Where the vein cuts the contact limestone and shale this alteration zone alongside the vein is narrow and unimportant, with amphibolic or sericitic alteration and the presence of chalcopyrite and zinc-blende intergrown with magnetite.

The following vertical distribution of ores is observable in the lodes:

Surface zone. Extends down from 50 to 200 ft. below the outcrop. Either barren or has oxidized ore.

Chalcocite zone. From 100 to 400 ft. in vertical extent, and more in places. Contains chalcocite and pyrite.

Pyritic zone. Begins 200 to 600 ft. beneath the surface. Contains pyrite, chalcopyrite, and zinc-blende.

In the chalcocite zone — the only one commercially important — magnetite has largely, though but rarely, wholly replaced the pyrite.

The disseminated ores are almost wholly confined to the lodes in the porphyry. Stopes of low-grade ore range from a few feet to 100 ft. or more in width; many are 200 ft. long and as much in vertical extent.

The orebody between the two Humboldt walls is 300 ft. long, up to 200 ft. wide, and stoped 200 ft. high. The ore mined is 2.5 to 3 per cent, but the mineralization gradually fades off unless cut off by fissures. "Prospecting for reserves must proceed laterally rather than toward extreme depths."

Payable deposits as a rule lie at high elevations. "Chalcocite ores and oxidized ores form a stockwork of seams in porphyry at the Metcalf mines, or in quartzite (at the East Yankee mine), or, occurring as disseminations in porphyry dikes (West Yankee lode and Shannon mine), in general correspond to the altered zones surrounding veins, as described above. All the orebodies of the region may be faulted by later displacement."

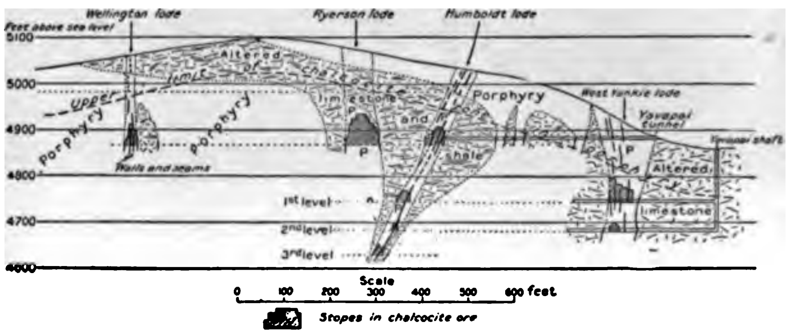


FIG. 124. – VERTICAL SECTION, YAVAPAI SHAFT, MORENCI. (LINDGREN)

The Coronado vein differs from the others, being a fault fissure with a 1000-ft. throw, between granite and quartzite, and followed for part of the distance by a later diabase dike. There is little or no gangue mineral, the pyritic ores being contained in altered porphyry, and the upper few hundred feet of the vein contains an enriched zone with chalcocite.

The Detroit Company and the Arizona Copper Company are working the low-grade bodies underlying Copper Mountain, the ores carrying from 3 to 5 per cent copper and needing concentration before smelting. The mines of this character include the Humboldt, Yavapai, Arizona Central, Copper Mountain, and West Yankee. The mining costs range from $1.50 to $2 per ton. The ores are of the character mentioned

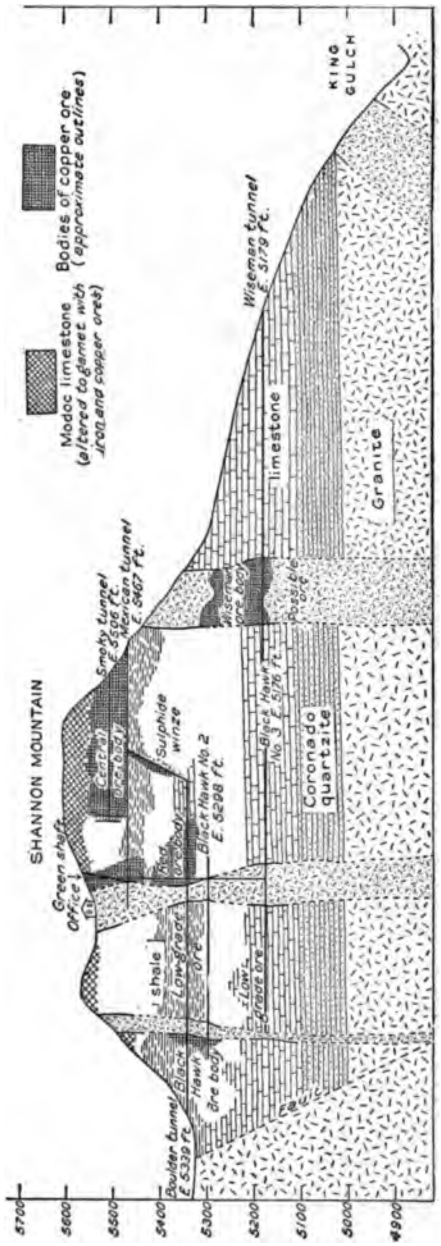


FIG. 125.—VERTICAL SECTION ACROSS SHANNON MOUNTAIN AND SHANNON MINE FOLLOWING BOULDER AND WISEMAN TUNNELS, CLIFTON-MORENCI. (AFTER LINDGREN)

above, consisting of decomposed porphyry, carrying finely disseminated pyrite and glance.

The Clifton smelter handled 177,248 tons of ore in 1904; 780,771 tons were milled, and 114,885 tons concentrates produced, valued at $4,851,362, or $42.23 per ton.

Silver Bell District. — The Imperial Copper Company owns the Mammoth, formerly known as the Old Boot mine, in Pima county. This mine is in the Silver Bell mountains, an isolated range northwest of Tucson, having an elevation of about 3000 ft. above sea-level. The orebodies are irregular lenses, running northwesterly in parallel shear planes in porphyry. There are prominent gossan cappings, and the granite porphyry is impregnated with copper sulphides along the limestone contact. The ores consist of pyrite, with chalcopyrite and occasional bornite, but there is also a copper-bearing silver-lead ore, consisting of galena, zinc-blende, and chalcopyrite, a combination difficult of reduction. In 1905 the Mammoth mine was 500 ft. deep, and the Union shaft 350 ft. deep.

The Jerome District, in Yavapai county, contains the United Verde mine and various copper properties south of Jerome. Unlike the other copper ores of the territory, those of the Jerome district contain relatively high values in gold and silver, the average ore treated at the smelters having a value of $18.95 per ton, and the copper ores producing 3854 oz. of gold in 1904.

But little is known of the United Verde mine. The ore is chalcopyrite, with some pyrite and zinc, and a carbonate gangue. It occurs as a great pipe 200 by 2000 ft. across, and mined for 1300 ft. in depth. This ore shoot lies in a shear zone in diorite, altered to schist, alongside of and near a contact with Algonkian rocks. To the north a great fault marks the face of the Colorado plateau. To the south the shear zone, marked here and there by gossan outcrops, is traceable for nearly 70 miles.[1] Though claims and workings are numerous, the district, aside from the Verde, has no large mines.

Plateau District. — The copper deposits of the Kaibab plateau[2] occur near Jacobs lake, 30 miles south of the Utah line. They are 16 ft. thick, of unknown width, and more or less continuous for 5 miles, with other outcrops of ore at various points along the plateau surface south to the Grand Canyon, a distance of 40 miles. The ore beds consist

[1] Manuscript notes furnished by Clarence King.

[2] E. P. Jennings, *Transactions* American Institute of Mining Engineers, vol. xxxiv, p. 83r

of white chert impregnated with malachite and azurite; small amounts of earthy cuprite, copper glance, and chalcopyrite having also been observed. The beds are also intersected by many small faults, the ore near these faults having been crushed and recemented by silica and copper. Jennings finds no evidence of copper in the Paleozoic strata below these beds, either along the fault which forms the western escarpment of the plateau or in the walls of the Grand Canyon, but mentions a few copper-bearing dikes with the usual contact impregnation of copper ore and copper-stained rock in the metamorphic series at the bottom of the canyon, nearly a mile below the copper-bearing strata.

The Grand Canyon mine is reached by the Grandview trail, which descends the canyon walls about 12 miles east of "Bright Angel," the point reached by the railroad. The mine is situated at the upper edge of the platform formed by the Red Wall limestone and 2500 ft. below the rim of the canyon wall. It is opened by a shaft 200 ft. deep and by a cross-cut tunnel that connects with the bottom of the shaft.[1]

"The ore is mostly blue and green carbonates with chrysocolla, but chalcocite has been found in the center of the larger masses, one of which, to judge by the opening left, must have been 8 or 10 ft. in diameter. There are no gangue minerals, and of other metallic minerals none was seen except a very little finely divided pyrite. One small specimen of chalcopyrite was seen, which was said to have come from the mine. The limestone country rock in the neighborhood of the deposit has been bleached and partially marbleized. This limestone is very much decomposed along a rather ill-defined shear zone, which trends about north 65 deg. east. Much of the decomposed portion is a white clay-like material, which the miners thought to be porphyry. I could, however, find nothing in or near the mine which I could consider as surely of eruptive origin.

"The ore is very irregularly distributed through the shear-zone material, generally in the form of strings and flakes of carbonate on cracks and thin seams. It sometimes occurs also in the limestone at considerable distances from the shear zone. At times it is concentrated into bunches, which often show a kernel of sulphide, or again it forms the lining of small caves or vugs, when it may assume very beautiful crystalline forms.

"The deposit is situated in the line of one of the north-south monoclinal folds which are characteristic of this region and which often pass into faults; but the strike of the shear zone is, as nearly as could be

[1] S. F. Emmons, *Bulletin* 260, United States Geological Survey, p. 231.

determined, at right angles to that of the monocline. A winze had gone down 40 ft. below the level of the upper tunnel and was still in ore, but the lower tunnel had not reached ore, though, as well as could be determined without instrumental measurement, it should already have cut the shear zone."

Numerous copper prospects and small mines exist in the region adjacent to Prescott.

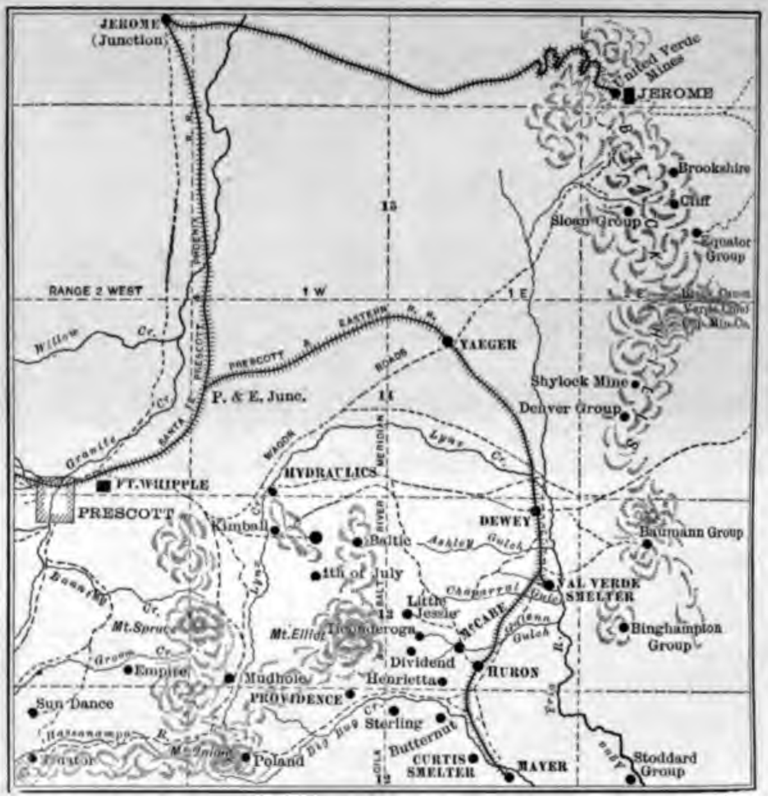


FIG. 126.—TOWNSHIP MAP SHOWING COPPER MINES OF THE PRESCOTT AND JEROME BELTS, ARIZONA

The Bradshaw mountains and vicinity contain numerous copper deposits whose location is shown on the map (Fig. 126).

According to Jaggar[1]: "No copper deposits of proved extent and

[1] *Geologic Atlas of the United States*, Folio 126, p. 10. United States Geological Survey, 1905.

value are yet known in this district, but several promising prospects were seen. Two types of copper deposits were recognized. One consists of distinct veins, carrying chalcocite, chalcopyrite, tetrahedrite, and in some instances bournonite, with a gangue of quartz, fluorite, and barite. The sulphide minerals are largely altered at the surface to chrysocolla and malachite. These veins carry silver values as well as copper.

"The second type consists of impregnation zones in schist, chalcopyrite, pyrite, and bornite, with more or less quartz replacing chlorite schist, or amphibolite, forming bodies of irregular and indefinite outline. Small stringer veins carrying the same minerals are also present in places, but the formation as a whole appears to be a direct replacement.

"The surface zones of such deposits are silicious schists, pitted and copper-stained with films of native copper, and sometimes of cuprite. Small gold values are also found in these deposits."

Copper deposits [1] also occur in the Triassic sandstones of the Navajo Indian Reservation, 125 miles north of Flagstaff and 50 miles east of the Kaibab plateau. The red sandstones are about 200 ft. thick, and overlain by 200 to 250 ft. of white sandstone forming the "White Mesa." The color is white, gray, or rarely red; it is cross-bedded and composed of well-worn grains of quartz sand from which most of the cementing material has been leached out, leaving it soft and friable.

The copper deposits consist of a replacement of the cement of one particular stratum of cross-bedded sandstone by chrysocolla, with some tenorite in grains or masses. Specimens contain as much as 32 per cent of copper. Generally the copper deposits are a few hundred cubic feet in size, and no strict line of demarcation is shown between them and the surrounding sandstone, the bluish-green color of the chrysocolla gradually fading into the white of the sandstone.

The ore is apparently associated with small vertical crevices or fissures. Some of the deposits show a distinct vein-structure, while others do not.

California

Nearly every county in this State contains copper deposits, but those of known economic importance are confined to four groups: (1) Shasta county; (2) the western flanks of the Sierra Madre; (3) the

[1] Described by H. F. Lunt, *Transactions* American Institute of Mining Engineers, 1903.

coast range; and (4) the deserts of southeastern California. At present time almost the entire production comes from Shasta cou in the north-central part of the State. The Foothill Copper belt the western flanks of the Sierras is nearly 400 miles long, and conta

FIG. 127.—INDEX MAP OF CALIFORNIA SHOWING COPPER DEPOSITS OF T STATE

many old and formerly productive mines. The coast range depos extend southward for 150 miles from the Oregon line, a number of c and formerly productive mines existing in Del Norte county.

The Foothill Copper Belt.[1] — The chief deposits of this region occur in two copper belts: one near Copperopolis, Calaveras county, the other the Napoleon-Campo Seco belt, 20 miles west of Copperopolis.

In the Copperopolis belt at the Union mine, the lode lies in black pyritous slate in a belt of amphibole schist, rocks identical in age and character with those of the Mother Lode, 12 miles to the east.

The Ione, Caledonia, and the Copperopolis mines lie in a narrow shale belt in a schist area just east of the western belt of Mariposa slates.

The Copperopolis vein is 3 to 40 ft. wide; the Union or Keystone vein has an average width of 15 ft. The latter carries a chain of lenticular masses of chalcopyrite, connected by ore stringers. Three orebodies have been worked, the largest, at the Union mine, being 2 to 40 ft. wide, 300 ft. long, and 600 ft. deep, pitching north.[2] The ore carries no gold or silver, and averages from 3 to 5½ per cent in copper.

The second or Campo Seco belt contains the mines of the Penn Chemical Company on the Mokelumne river, 20 miles northwest of Copperopolis. The vein contains chalcopyrite and pyrite, with a trace of zinc, and low values in gold and silver, in a gangue of talcose schist, clay, and quartz. A quartz porphyry dike accompanies part of the vein. The deepest development in 1905 was 550 ft.

The Napoleon, the oldest copper mine of the state, is nine miles southwest of Copperopolis. The ore course is 100 ft. wide, and consists of diabase and talcose schist. The dip is 62 deg. and the vein developed to 250 ft. in depth.

At Clovis, Fresno county, the Fresno Copper Company have erected a smelting plant with two furnaces and a converter plant, to treat the ores. The vein is said to be 30 ft. wide.

The Shasta Copper Belt. — The most important copper mines of California are in the hills about the northern end of the Sacramento Valley, in Shasta county. The deposits occur in a wide and very irregular belt of igneous rocks, breaking through or covering sedimentary rocks of various ages, from Devonian to Triassic. The igneous rocks are largely volcanic lavas, and like the sedimentary strata have been compressed, folded, faulted, and sheared. The orebodies occur in the sheared rhyolite, which locally resembles slate. The shear zones in places contain irregular bodies of sulphide ore, varying in size from

[1] *Geologic Atlas of the United States*, Folio 11.

[2] See "Copper Resources of California," *Bulletin* State Mining Bureau, and Mother Lode Folio, United States Geological Survey.

coast range; and (4) the deserts of southe
present time almost the entire production
in the north-central part of the State. Tl
the western flanks of the Sierras is nearly 4

FIG. [illegible] INDEX MAP [illegible]

many old and former [illegible]
extend [illegible]
and formerly [illegible]

mere films and nodules to masses many hundreds
are two producing areas, the Iron Mountain distr
Hill, the former west of the Sacramento river, th
Pit river. The Iron Mountain belt is the most
from Iron Mountain for 25 miles northeast, wi
two miles, in which the mines of the Mount
Balaklala Company, Trinity Copper Compa
Mining Company, Summit, and several lesse
shown on the map (Fig. 128). The country
is essentially the same, being chiefly an o
with a small proportion of andesite and tuff.
these rocks, in some places near the sedimen
them, and only in shear zones, in which th
These shear belts are limited, the longest b
The deepest mine is 1000 ft., and the extent
determined.

The Bully Hill district contains two ore
and Copper City, in an area 2 by 3 miles
two shear zone lodes. The eastern is the
mine; the western is the Anchor, of the B

The Delamar lode runs north 10 deg. east
westward. With interruptions it is trac
The solid ore is from 4 to 12 ft., and som
for 800 ft. in depth. The shear zone is
of greatly altered basaltic rock (so-calle
dike or the contact between it and the
the mineral.

with dip of 84 deg. southwest, agreeing closely with that of the Spr
Eagle, and transverse to the Iron Mountain trend.

The Balaklala outcrop is one of the most prominent of the region. is traceable for over half a mile, with a course of north 70 deg. east, an northwest dip but little steeper than the hill slope. The property is c of the great low-grade mines of the belt, but the ore is more silici than that of the Mammoth or the Iron Mountain mines.

The principal orebody thus far discovered is the Windy Can developed for 1000 ft. in length, 500 ft. on the dip, and showing thickness of 5 to 20 ft. The orebody is incased in clay, showing sm lenticular nodules of ore, and surrounded by altered and but sligh pyritized rhyolite. The ore is low-grade, consisting of pyrite, so chalcopyrite, and a little quartz.

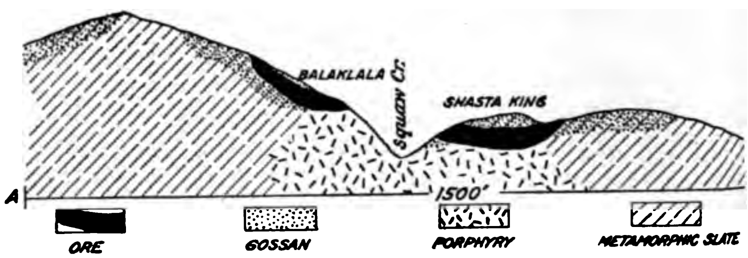


FIG. 130.—CROSS-SECTION OF OREBODIES, BALAKLALA, CALIFORNIA

The Shasta King lies opposite and below the Windy Camp mi and across Squaw creek. The orebody is irregularly basin-shape some hundreds of feet wide, with north and south axis rising nort ward, and is delimited by a sericite gouge a foot thick. The ore identical with that of the Balaklala, and limited by shear fissure The owners, the Trinity Copper Company, claim to have 800,000 to of workable ore blocked out. The ore will probably average abo $2\frac{1}{2}$ per cent copper.

The Mammoth ore lode runs north 80 deg. east, and is traceab for a half-mile. The orebody is the largest one of the entire distric It shows a length of 300 ft. and a developed depth of 200 ft. On t main level the dip is 30 deg. northwest. The ore consists of pyrit with patches and streaks of chalcopyrite, and considerable sphalerit There is little or no quartz. The mine belongs to the United Stat Mining Company, and is a large producer.

Northeast of the Mammoth is the Golinsky. The orebody extends f

50 ft. with a north 70 deg. east course, and a developed depth of 100 ft., running parallel to the Mammoth. A mile to the southwest of the Mammoth a shear zone of impregnated rock, on the Friday and Lowden properties, shows small bodies of similar ore.

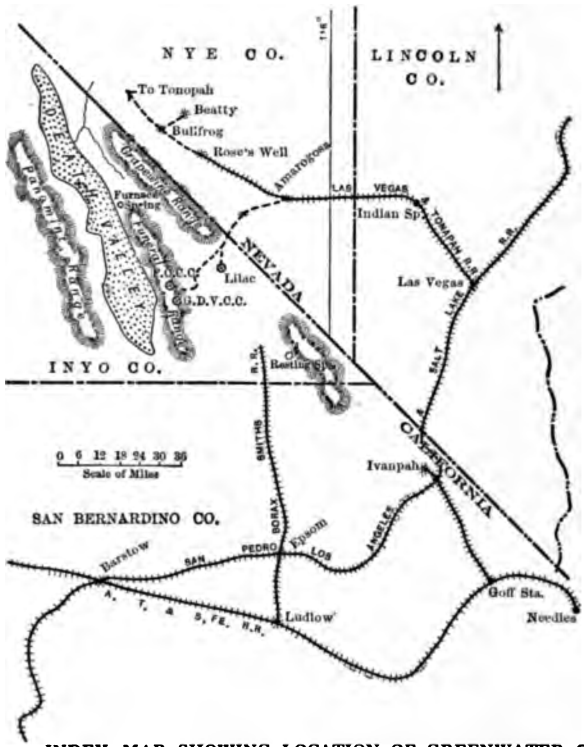


FIG. 131. — INDEX MAP SHOWING LOCATION OF GREENWATER COPPER DISTRICT, CALIFORNIA

The Greenwater District in Inyo county, east of Death Valley, has lately come into prominence. The district lies on the flanks of the Funeral range. The region is underlain by granite and granitic porphyry with rhyolite flows and tuffs, capped on a few summits by remnants of basalt flows. No sedimentary rocks occur. There is a belt of mineralized country said to be thirty miles long. The ores are high-grade and silicious, and consist of carbonates. They occur in shear zones running southwest through the granite, and are in streaks of about a foot to several feet in width. The granite is permeated with specularite scales and iron-stained belts occur. There are no producing mines.

COLORADO

The copper produced in Colorado is obtained mainly as a by-pro uct of the precious metal ores treated in custom smelters, thou copper ores occur in nearly every part of the State. The productic for 1905 was 9,850,827 lb. Lake county supplied 4,486,117 lb., ar San Juan 2,274,106 lb.

The Pearl District is 20 miles southeast of Encampment, Wy The rocks resemble those of the Wyoming district save that quartzi is lacking, and the prevailing rock is a red or gray granite, cut by pe matite dikes. The ore consists of chalcopyrite, intergrown with hor blende and calcite of the same age, and carrying considerable sphaleri as an accompaniment of hornblende schist. The Mount Zirkel deposit in a shattered granite pegmatite and gneiss. According to Spence the veins are thin and the ores associated with hornblende rocks in whi they were formed by segregation during the general metamorphis which produced the banding of the country rock.

The Cashin copper mine, owned by the La Sal Copper Minir Company, is the most important producer of Montrose county, soutl western Colorado.[2] It produced 732,740 lb. copper and 363,778 o silver from 1899 to 1906. The mine is 70 miles west of Placervill the nearest station on the Rio Grande Southern. The region is pa of the plateau country of southeastern Utah and northern Arizor and New Mexico, and is underlain by a thickness of nearly 1400 f of horizontal Cretaceous and Jurassic sandstones, resting on Triass Red Beds. These rocks are strongly fissured and faulted.

The ores consist of crushed sandrock and kaolin containing sma specks of copper sulphides, with veinlets of silver-bearing covellit chalcocite, and bornite, with a little calcite and barite. Oxidize copper minerals, native silver, and argentite occur in pockets near th surface. Native copper also occurs.

The ore deposits occur in a fissure running north 20 deg. east an cutting the La Plata sandstone, a formation 600 ft. thick that overli the Red Beds. This fissure is from 1 ft. to 20 ft. wide, and trac able two miles or more. The walls are not always distinct, and th green copper stains extend into the wall rock.

Grand Junction District. — Copper ores of economic value a

[1] "Copper Deposits at Pearl, Colo.," *Bulletin* 213, United States Geological Surve 1902, p. 163.

[2] W. H. Emmons, *Bulletin* 285, United States Geological Survey, 1906, p. 125.

nd in the Unaweap Valley, a deep cut across the Uncompahgre lift about 15 miles south of Grand Junction, Colo. A series distinct fault fissures cross red sandstones, which in some cases uld be traced down into the underlying granite exposed in the lley bottom. Some of the lower beds of the sandstones are quite lcareous, passing into a deep red impure limestone. The vein issures are a few feet wide and carry fragments of the red limestone ven well down into the granite. The ore is largely chalcocite and bor-ite, with some carbonates, resulting from the alteration of chalcopyrite, in a gangue of quartz and calcite with occasional fluorspar. It is said the ore carries values in gold and silver. The principal orebodies occur where the fissures cross the calcareous beds near the base of the red sandstones. Here the ore spreads out for a considerable distance laterally, while above and below the metallic minerals decrease in quantity. In one tunnel in the granite, which follows the vein for about 300 ft., only occasional small specks of copper ore were seen.[1]

From Telluride westward to Paradox and Sinbad valleys, uranium, vanadium, and copper ores are found as impregnations of the lighter colored sandstones immediately overlying the Red Beds or Dolores formation. They are, however, not universally or uniformly distributed, but occur where there is a faulting or fissuring of the beds. The copper impregnations in the sandstones are usually spherical concretions or nodules, blue or green in color, averaging about the size of a pea, while the uranium mineral, carnotite, is yellow and forms streaks running generally parallel to the bedding. Vein deposits of copper ore were also found, the veins being fault fissures, generally of slight displacement, carrying crushed sandstone and calcite, with argentiferous chalcocite and some copper carbonates. The latter impregnate the sandstone country rock in specks, and sometimes color the entire bed green to a distance of 100 ft. or more of the vein. Uranium minerals are observed for a distance of 100 miles across this region.

IDAHO

Idaho contains many undeveloped copper deposits in different counties, but the production has come almost entirely from the White Knob mine of Custer county, and the Snowstorm mine in the Cœur d'Alene district. The State produced 11,720,000 lb. copper in 1906.

[1] S. F. Emmons, "Copper in Red Beds of Colorado Plateau," *Bulletin* 260, United States Geological Survey, 1905, p. 227.

The White Knob mine, near Houston, in Lost River Valley, was formerly the largest producer of the State. The ore occurs as a deposit between granite and limestone; the trend of the contact being north and south, with the limestone lying to the east of the granite. On the surface the ore-bearing zone is 1200 ft. in length, and has a maximum width of 400 ft. The minerals are hematite, magnetite, chalcopyrite, pyrite, and a little galena, in a gangue of garnet and coarsely crystalline calcite. A porphyry dike occurs on the contact, complicating the geological relations. The oxidized zone is very deep, sulphides not having been encountered until the depth of 600 ft. was reached in the shaft.[1]

Cœur d'Alene.—The chief productive property of this district is the Snowstorm mine, east of Mullan. The deposit occurs in Algonkian (Revett) quartzite, according to Ransome,[2] and is an impregnated cupriferous zone conforming to the bedding planes, the strike being north 60 deg. west, and dip 65 deg. southwest. The orebody varies from 10 ft. to 35 ft. in width, and is 400 ft. long. The ore below the oxidized zone consists of glance and bornite specks in quartzite, but in places shows stringers and patches of chalcopyrite. The quartzite is not particularly fissured and does not appear to differ from the rock of the foot and hanging walls. The greater part of the mineralized quartzite contains about 4 per cent copper, with 6 oz. silver and 0.1 oz. of gold per ton. The ore contains about 90 per cent silica, no iron, and little alumina. The ore shipped is used mainly for converter linings, being too silicious for most smelters to handle otherwise. The lean ore is leached at the mine.

The St. Joe river basin, Idaho, has many copper prospects, which with the producing Monitor mine give indications that the district may become an important copper producer. The most important belt lies along the summit of the range south of and easily accessible from the Northern Pacific Railway. The ores occur in east-west fault fissures, near but not adjacent to intrusive bodies of diabase, and are all in Algonkian (pre-Cambrian) rock, the Cœur d'Alene series of argillite and slates. The lodes have projecting ironstone outcrops, composed of rock fragments cemented by limestone and hematite, often stained by copper carbonate. The fissure zone dips at 80 deg. north.

The Monitor mine, five and one-half miles from Saltese, Mont., shows an orebody at least 10 ft. wide, with chalcopyrite associated

[1] W. Darlington, quoted by Lindgren, "Genesis of Certain Contact Deposits," *Transacti*[illegible]an Institute of Mining Engineers, 1901.

[2] [illegible] United States Geological Survey, 1906, p. 301.

with pyrrhotite at a depth of 125 ft. The ores carry \$3 to \$9 per ton in gold, and the 500 tons of ore shipped ranged from 10 to 40 per cent copper. The shaft was 300 ft. deep in 1905.

The Bald Mountain ledge, two and one-half miles northwest of the Monitor, runs east-west, and dips at 60 deg. north. The ledge is from 1 to 9 ft. thick, and contains brecciated quartzite like the wall rock. A tunnel driven on the vein opens an ore shoot 100 to 200 ft. long, and several feet thick. The ore is siderite, containing scattered chalcopyrite. The gangue of the ore is crushed country rock cemented by quartz calcite and siderite, with iron and copper pyrite through it.[1]

At *the Loon Creek district* in Custer county the Lost Packer Mining Company mines a fissure vein in granite and rhyolite. The vein is 10 to 15 ft. wide and carries a pay streak of about 2 ft. in width that is clean and well defined. The ore consists of massive chalcopyrite, with 20 per cent copper and about 2 oz. gold. Outside of the pay streak the vein is low-grade, running, it is said, about 3 per cent copper and \$5 to \$7 gold. A blast furnace capable of handling 100 tons daily has recently been installed.

The Seven Devils District, in the western border of the State, contains contact deposits which have been described by Lindgren as follows:[2]

"In the Seven Devils district and in the adjacent Snake River Canyon copper deposits are very abundant. There is in that vicinity an extensive series of Triassic basic lavas, with intercalated layers of slate and limestone. There is also diorite intrusive in these beds. All of these igneous rocks apparently contain copper which was easily concentrated into deposits of various kinds; some, fissure veins; others, zones of impregnation; others, contact deposits.

"In the locality of the original discovery in the Seven Devils the copper occurs in typical contact deposits. Small masses of limestones are imbedded in a later, intrusive diorite; at the contact, and usually in the limestone, are found irregular bodies and bunches of bornite, chalcocite, and a little chalcopyrite, the ores containing, say, 10 oz. of silver and a little gold per ton. The limestone at the contact is coarsely crystalline and contains, associated with the ores, abundant garnet, epidote, quartz, calcite, and specularite. The copper sulphides, as shown by their intergrowth, were certainly formed at the same time as the gangue

[1] A. J. Collier, *Bulletin* 285, United States Geological Survey, 1906, p. 129.

[2] "Character and Genesis of Certain Contact Deposits," "Genesis of Ore Deposits," p. 722, American Institute of Mining Engineers.

of Lake Superior. It is 40 miles across from east to west, and projects about 70 miles northeastward into Lake Superior. The central portion of this peninsula is formed of a succession of lava beds with interbedded layers of sandstone and conglomerate. The lava is a dark basaltic rock, having the texture of diabase, and most conveniently designated as trap. Light-colored quartz porphyries or rocks corresponding to andesite in composition also occur. The conglomerates are composed of rounded fragments of igneous rock, the light-colored reddish and yellowish quartz porphyries predominating. The beds dip westward at angles varying from 35 to 70 deg. The entire series has a thickness of from 25,000 to 30,000 ft. and is flanked on both sides by conglomerate and sandstone. To the west these sediments appear to be conformable, dipping with the lava beds. To the east there is a fault and the sandstones are nearly horizontal.

The trap area forms the so-called Copper Range, a belt from 4 to 6 miles wide. The different members of this trap rock series vary from a few feet to 100 ft. in thickness, the individual lava flows or layers being distinguished by the amygdaloidal or vesicular nature of the upper portion, and are oftentimes separated by beds of conglomerate. The igneous rocks have altered to a dark green rock, in which the original hornblende and augite have been changed to chlorite and epidote, and the holes or vesicles filled by quartz, calcite, and other minerals, including native copper.

Both the amygdaloids and the conglomerates are heavily impregnated with epidote. The copper occurs in crystalline form, and as casts or fillings having the shape of the cavity which it fills, and rarely coats and replaces calcite. The conglomerates often inclose seams of fine-grained sandstone, but in such cases the copper impregnation is in the conglomerate. The conglomerates consist largely of chocolate-colored and reddish porphyry, whose character is shown in Fig. 135 together with a few fragments of diabase and amygdaloid. As shown on the general map of the district (Fig. 134), these lodes outcrop as ledges having a general northeast course; owing to glacial erosion and the covering of the country by drift, long outcrops are seldom seen.

The chief production of the district comes from the Calumet and Hecla conglomerate. This bed is from 12 to 25 ft. thick, and has a northwest dip of 36 to 39 degrees. The ore is not continuous throughout the entire extent of the bed, but is confined to an ore shoot of great length, that of the Calumet and Hecla property being said to be productive for two miles in length, and in this distance there are but few lean spots.

The diabase beds have the characteristics of extrusive lava flows whose upper surface is often scoriaceous, giving rise to the term "ash bed." Such rocks form many of the workable "lodes." In the uplifting of the entire series of rocks there has been dislocation and slipping along bedding planes, besides some cross faulting.

CALUMET AND HECLA CONGLOMERATE, THIN SECTION. SCALE ORDINARY LIGHT. NATIVE COPPER IS BLACK. (Irving)

fragments of matrix. 3, quartz. 4, feldspar of porphyry. 5, fragments
7, amygdaloid fragments. 8, original native copper. 9, calcite

Monograph V, plate XV, p. 127, U. S. Geological Survey.

The distribution of the copper in the different ore-bearing beds i
depends upon the structure of the rock. In the Quincy mine the hang
... is richest, this portion being the most permeable. In th
... the copper is somewhat uniformly disseminated through

out the amygdaloid. In the Baltic mine the copper is irregularly distributed and the ore channel appears to be a sheet zone, the fracturing extending beyond the limits of the amygdaloid layer and into the incasing trap. Slip planes and flat cross joints indicate movements, a cross vein at No. 4 mine extending for 200 ft. across the beds, and holding copper with quartz and calcite. Cross veins, though frequent, do not usually extend beyond the limits of the ore bed, and conform in strike to that of the main ore bed. The occurrence of copper in these cross veins and of sheet copper along cross joints in the footwall indicates migration of material after the original ore deposition was completed. Lump or mass copper is common, and can often be recognized by the light-colored patches of decomposed rock surrounding it.

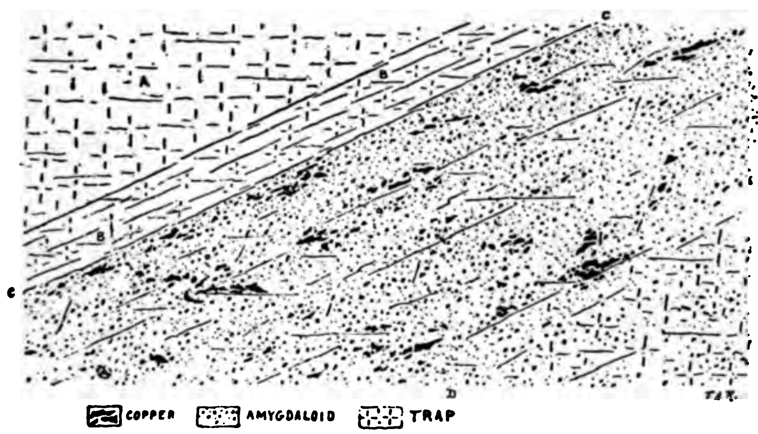


FIG. 136.—SECTION OF QUINCY AMYGDALOID LODE. (RICKARD)

Joints and long slip planes are common and may mark a change in the copper content, the rock on one side being richer. As a rule, the cross courses consist of bands from a few inches to 2 ft. wide of crushed rock seamed with white calcite. They dislocate the copper lode but slightly and seldom contain copper. In general, the mineralization of the amygdaloidal lodes is diffused and irregular, and the richer rock lies against the hanging wall.

The bed known as the Allouez, or as the Boston and Albany conglomerate, is from 8 to 25 ft. thick. It is underlain by 3 or 4 ft. of sandstone, resting in turn upon trap rock, and it is overlain by a foot of clay gouge with 4 to 5 ft. of shattered trap rock above it, the normal hard trap rock forming the hanging-wall bed. Like amygdaloid, the conglomerate is also traversed by well-marked joi and slips. The pebbles range in size from a pigeon's egg to bould as large as a man's head, the rock composed of smaller pebbles bei more favorable for copper, the best ore occurring where the cementi material is less firm, the copper favoring the permeable rock. In t Franklin mine the footwall sandstone thins out in depth, and the copp extends from the conglomerate into the underlying amygdaloid. T dip is about 18 deg. The ore-bearing beds sometimes lie close togeth for example, the Osceola conglomerate lies 800 ft. east of the Calum and Hecla conglomerate. A knowledge of the geology is essential successful prospecting. The trap beds are so nearly alike that ide tification is ordinarily impossible, but occasionally some mineralogi characteristic will serve as a guide, as, for example, the footwall of t Kearsage amygdaloid is a bed marked by large feldspars. Usua the amygdaloid layers weather more readily than the compact trap i casing them, and hence show infrequent exposures, and are covered wi drift and soil. The conglomerate beds form occasional outcrops.[1]

In the early history of the district the fissure veins alone were worke and yielded great quantities of mass copper. The mine workings ha shown that the fissure veins pinched out at a depth of between 2000 ar 3000 ft., and cross the formations transversely. Masses of copper several tons' weight are found in Quincy and other amygdaloid lode but nothing so large as those of the fissure veins.

The remarkable regularity of the bedded lodes is shown by the fa that on August 5, 1895, Tamarack shaft was started, and it was e pected to cut the Calumet conglomerate at 4665 ft. on January 1, 190 It was cut at 8 ft. less in depth and eleven days sooner.

The Allouez or Boston and Albany conglomerate lode averag 16 to 18 ft. thick in the Allouez mine. The lode as mined carri 5 to 8 per cent waste from bars or crossings of trap rock that gas across the lode. The copper values are higher adjacent to thes trap bars. The ore averages 2 per cent in the Allouez mine. Th rock is hard and wears out stamp shoes in one-tenth the time tha the amygdaloid ores do. The copper of the lode is very regularl distributed, but there is an enrichment where the rock is soft.

This lode is worked in the Allouez and Franklin, Junior, mines being stoped to a depth of 2100 ft. in the latter. The lode is als

[1] T. A. Rickard, "The Copper Mines of Lake Superior."

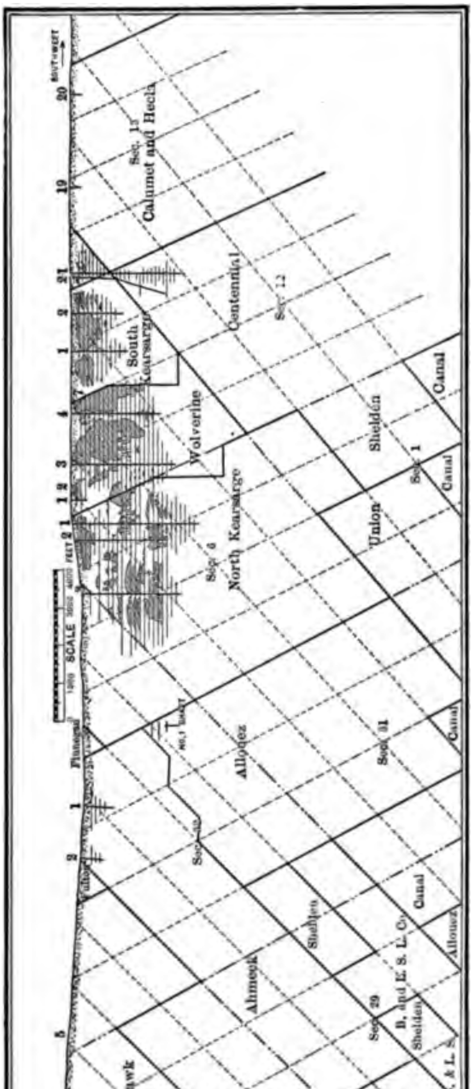


FIG. 137.—LONGITUDINAL SECTION OF KEARSARGE LODE. (AFTER EDWARDS)

worked in the Delaware, and with the Ash Bed is the only lode c worked north of the Mohawk.

The Ash Bed lode was extensively explored by the Phœnix co pany, but proved unpayable. It yielded very rich ores in the ea days at intersections with cross fissure veins in the property of t name.

The Atlantic lode is wide and has the copper very uniformly d tributed, but in minute particles, so that great care is needed in m ing. The ore averages between 0.55 and 0.80 per cent.

The Baltic is the easternmost and lowest of all the lodes min It is a thick lode and apparently a shear zone (Lane). The lo is worked by the Atlantic, Superior, Erie, Ontario, Challenge, Balt and Trimountain mines.

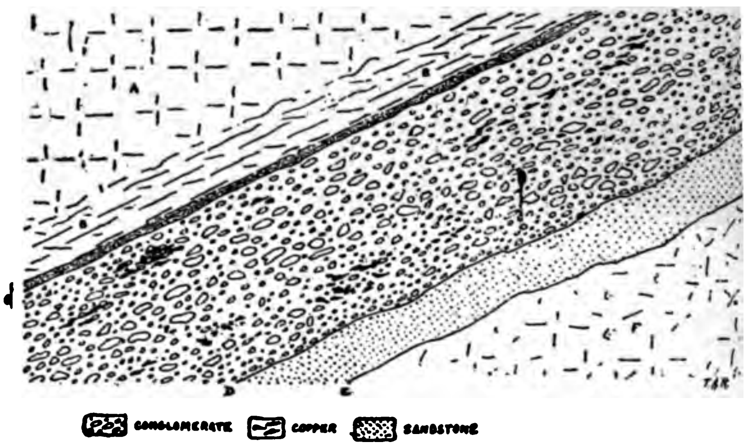


FIG. 138.—SECTION OF THE FRANKLIN, JR., CONGLOMERATE LODE, MICHIGAN. (RICKARD)

Branch or South Branch Lode. — This is a contact vein lying on th Minnesota conglomerate, and is the same as the north vein of th Rockland company. The lode is 6 to 12 ft. wide and forms the chie source of supply for the Michigan company.

The Butler lode is worked by the Mass company. It is 400 ft. east of the Knowlton.

The Calumet conglomerate has already been described. It has been developed by the Osceola company; but only a few acres proved payable, and the lode is unprofitable outside of the Calumet and Hecla ground or its underlay owned by the Tamarack.

—This amygdaloid lies 140 ft. north of the Minnesota
es 8 ft. thick and has a dip of 47 deg. in the Michi-
is also worked by the Mass Copper Company and

—This lode is 3 to 5 ft. thick, but widens when
come in. The values are only in patches, which are
ng in the drifts. The lode is worked by the Victoria
ft 2089 ft. deep. The lode is 400 ft. horizontally east
It is probably identical with the Mead vein.
lode is worked by the Victoria company.
d Portage lode is worked by the Isle Royale mine to the
el. The Isle Royale is worked by the mine of that

rsarge conglomerate is, next to the Calumet conglomerate, productive lode of the entire district. It is cupriferous in ount for a distance of 11 miles, though the amount is variable t places. It is worked by the Mohawk, Ahmeek, Allouez, arsarge, Wolverine, South Kearsarge, Centennial, Calumet, mseh properties. It lies 200 to 300 ft. horizontally north- the Wolverine sandstone, making its identification easy. er it has a characteristic mottled footwall. At the Mohawk per levels show an enrichment of copper coincident with a l softening of the rock. The lode averages 1 per cent copper Mohawk mine. At the Ahmeek the lode shows a very uni- distribution of the copper. The lode averages 15 ft. thick. It 311 ft. east of the Greenstone on the Delaware property, and ft. horizontally east of the Kearsarge conglomerate (Hubbard).

he Knowlton lode is 8 ft. thick at the surface and 18 ft. in the e levels. It is worked by the Adventure, Aztec, Algomah, and s companies and shows good values, especially in the first-named.

The Mass mine works six parallel cupriferous beds. The Misery er lode is developed by the Wyandotte company, but is lean.

The Mayflower company works a series of unnamed and uniden- tified lodes, some 3000 ft. east of the Kearsarge amygdaloid, all of them showing bunches of copper ore.

The Minnesota conglomerate is a contact vein opened by the Michigan company.

The North Minnesota lode runs from the Calico lode at the out- crop to the Minnesota lode in depth.

The North Vein is an excellent producer. It averages $6\frac{1}{2}$ ft. thick, varying up to 12 ft. with 3 or 4 excellent shoots (courses) of copp It is worked by the Michigan company.

The Norwich and parallel Meads, the latter probably identi with the Evergreen, are worked by the Copper Crown company.

The Osceola amygdaloid is extensively mined by the Calumet a Hecla, Osceola, and Tamarack mines. It proved worthless on t Centennial company's ground.

The Pewabic is an ash bed and the main lode of the Quincy mi This lode has yielded much mass copper, 40 per cent of its producti being mass copper at one time, while in 1905 only 5 per cent w mass and 95 per cent fine but uniformly distributed copper. It mined by the Quincy and Rhode Island companies and formed t main source from which the Old Franklin company derived its copp The Quincy mine is next to the Calumet and Hecla in point of di dends paid ($15,220,000 to end of 1905).

The Superior lode is 45 ft. wide, dips at 60 deg. at the surface a 45 deg. at 180 ft. down, and shows good values. The Winona lode presumably the same as the Baltic. It carries good values in t King Philip mine, but is lean in the Wyandotte and Elm River. Th Wolverine lode carries 16 to 30 lb. of copper per ton (1905), and th ore mined has but 5 per cent waste.

Missouri

Copper ore has been found at several places in southeastern Mi souri, including Ste. Genevieve, Mine La Motte, and near Sulliva The most important occurrence appears to be at Fredericktown, ne Mine La Motte, where the North American Lead company bega production on a considerable scale in 1907, having erected a smeltin works. The mine at Fredericktown is situated at the southern edg of the disseminated lead district of southeastern Missouri, and at thi edge the dissemination of galena, which is characteristic of the re mainder of the district, has given place to a dissemination of nickel cobalt-copper pyrites. According to information communicated b the company in March, 1907, its ore averages about 6 per cent cop per and 3 per cent cobalt plus nickel. At that time the compan was producing about 5000 lb. of blister copper per day. Althoug a little copper occurs with the disseminated lead ore elsewhere ir southeastern Missouri, this is the first instance where the quantity ha been large enough to warrant a special plant for its recovery.

MONTANA

Montana is the greatest copper-producing State of the Union, and Butte the greatest copper-mining district of the world, producing one-third of the world's supply of copper. Copper ore is mined in several other districts in various parts of the State, but mainly for the gold or silver values.

The Montana copper production amounted to the enormous total of 308,949,818 lb. in 1905, all but 460,298 lb. coming from the Butte mines.[1] The Butte ores also furnish 18 per cent of the gold and 80 per cent of the silver production of the State, the gold-copper ores of Beaver Head, Meagher, and Jefferson counties furnishing but 17,300 oz. of silver out of a total of 10,250,000 oz.

FIG. 139.—INDEX MAP SHOWING KNOWN COPPER DEPOSITS OF MONTANA

The Butte district is situated in southwestern Montana, in the central part of the Rocky Mountain region. The city, which is built about and over the mines, is the largest settlement of the State, while the neighboring city of Anaconda, 20 miles distant, is a dependent, having been built for and supported by the reduction of the Butte ores. Smelting the Butte ores is also the largest industry of the city of Great Falls.

[1] United States Geological Survey, Mineral Resources for 1904, on the "Gold and Silver Production of the United States."

Three transcontinental railways run to Butte, and its traffic surpasses that of all the other cities of the State combined.

Originally named Summit Valley district, a name which is still retained in official records, and which is significant of its situation almost upon the transcontinental divide, where the waters of the Pacific and Atlantic separate, it is now universally known as Butte, a name derived from a sharply conical hill that rises abruptly above the barren hillside on the edge of the city and forms a prominent landmark. The area comprising the district is a now barren hillside on the northern side of a flat valley bottom. This level valley is inclosed by an abrupt mountain range, forming the continental divide on the east, and the snow-capped peaks of the Highland Mountains on the south. To the westward a low plateau, now cut through by Silver Bow creek, separates this valley from the great lake-bed area of the Deer Lodge Valley.

Development of the Region. — The Butte district of Montana is today the most important copper-producing area in the world, the product aggregating 3,929,200,000 lb. to the close of 1905, with a total value of $491,491,000. The discovery of the copper veins of Butte was not made until after the district had acquired some prominence for its gold placers, and subsequently as a silver camp. The placer gold was first worked in 1863, the date of greatest activity being in 1867, since which period the production of placer gold has become quite insignificant.

In 1864 the first lode location was made upon a vein now known as the Travona. This was the beginning of a period of very prosperous silver mining, and the district became the center of energetic operations, large mills being erected, with a considerable output of silver as a result. The climax of the production of silver ore was reached in 1887, when the different mills treated about 400 tons of ore per day and the smelters an aggregate of about 100 tons per day, the average yield being about $25 per ton in gold and silver. This period of active silver mining continued until 1892, when in common with other silver camps of the country the Butte district suffered a crushing blow.

In the year 1881 the Dexter mill was leased by Marcus Daly, for the newly organized Anaconda Silver Mining Company, and 8000 tons of oxidized silver ore, from the Anaconda ledge, was treated in this mill, yielding about 30 oz. of silver to the ton. The ore contained just enough copper to make it unnecessary to add bluestone in the raw amalgamation, but the resulting bullion was very base, sometimes running only 400 fine. In working the vein a drift running northeast at a depth of 100 ft. ran into a seam of copper glance a few inches wide. Mr. George Hearst, visiting the district about 1882, selected the site of the present Anaconda shaft as the most suitable place for future development. At a depth of 300 ft. a crosscut run from the shaft encountered 5 ft. of copper glance, and the ore was extracted and shipped to Swansea. During these early years the copper ores showing on the surface of several of the claims were receiving attention, and in 1867 an effort was made to smelt some of the ore from the Parrot lode.

To Senator W. A. Clark is due the first successful development of the copper veins of the district. In 1872 and the succeeding two years he began development work on the original Colusa, Mining Chief, and Gambetta claims. The ore extracted was shipped 400 miles in wagons to Corinne, Utah, thence by rail to the East, some of it also going to Swansea.

One of the purchasers of this ore was the Boston and Colorado Smelting Company, located at Black Hawk, Colo., and in 1879, at Mr. Clark's suggestion, this company formed the Colorado and Montana Smelting Company and erected reduction works on the present site of the Colorado Smelter, thus furnishing a local market for the copper as well as the silver ore of the district. This smelter gave a great impetus to copper mining in the district, as previously shipments containing 35 per cent of copper from the Green Mountain claim gave no profit to the shipper after the cost was paid, although the gross value of the ore was $130 per ton in copper, the average price of that ore being 18⅝c. per pound. In silver the ore carried not less than $50 per ton, but the works charged a high price for treatment, owing to the presence of arsenic, which made the metal brittle.

Soon after the erection of the Colorado Smelter, the Parrot, Montana Copper, Clark's Colusa, and the Bell Company began smelting operations. The matte produced by these works was shipped to Eastern markets for refining. In 1884 the Anaconda Smelter began operations, followed rapidly by the formation of the Butte Reduction Works, Boston and Montana, Butte and Boston, and Montana Ore Purchasing companies. The completion of the Utah Northern Railway from Ogden to Butte, in December, 1881, and the connection of this railroad with the Northern Pacific at Garrison in 1893, and the coming of the Montana Central, part of the Great Northern system, in 1888, and of the local branch of the Northern Pacific in 1889 — all added to the prosperity of the camp.

In the history of Butte the metallurgical advance in the treatment of the ores has been very steady; the free-milling silver plants gave place to chlorination and roasting, and these in turn to other improvements, so that the ores which could be profitably treated became lower and lower in grade. With the great decline in silver of 1892–1893, the silver-mining industry of the district became less and less important, until, in 1896, all the large plants were closed down, and since that time the mining of silver ores has been of relatively slight importance and has been carried on chiefly by leasers working in the old properties. The importance of Butte as a producer of silver and gold at the present time is due to the fact that the copper produced contains 0.0375 oz. of silver and $0.0025 in gold for each pound of copper produced, or approximately 2½c. in the precious metals for each pound of copper.

TABLE SHOWING THE DAILY PRODUCTION AND NUMBER OF POUNDS OF COPPER IN THE ORE MINED IN SEPTEMBER, 1906, BY THE DIFFERENT COMPANIES OPERATING IN THE BUTTE DISTRICT

MINING COMPANY	TONS ORE	COPPER, LB.	TONS DAILY	LB. PER TON
Boston and Montana	96,000	7,296,000	3200	76
Anaconda	111,000	7,992,000	3700	72
Butte and Boston	18,300	1,281,000	610	70
Washington	16,800	1,159,200	560	69
Parrot	11,160	691,920	372	62
Trents	15,900	1,113,000	530	70
North Butte	30,000	3,900,000	1000	130
Red Metal	28,500	2,080,500	950	73
Original	29,100	2,151,000	970	74
East Butte	3,750	337,500	125	90
Pittsburg and Montana	4,020	402,000	134	100
Miscellaneous	15,000	1,050,000	500	70
		29,456,520		

The production for 1906 was 299,850,000 lb. of copper.

The rocks of the ore-bearing area are all igneous, the district forming part of an extensive region of Tertiary igneous activity. The prevailing rock, and the one in which all the veins occur, is a dark basic granite, technically known as quartz-monzonite, which is a part of a great mass of granitic rock extending from the snow-capped Highland Peaks, seen 20 miles south of Butte, northward to Helena. This great mass of intrusive igneous granite is surrounded by altered limestone and other sedimentary rocks, and is in part covered by dark-colored andesite (both massive and fragmental varieties) of earlier age. Neither sedimentaries nor andesite occur in the district. Throughout the Butte mining district the granite is remarkably uniform in color, texture, and composition, and the name Butte granite has been applied to it. This rock is cut by dikes and irregular intrusions of the Bluebird granite, a white aplite[1] composed of quartz and feldspar, with a little mica. The rock, though intrusive in the granite, is supposed to have separated from the same magmas as the Butte granite and to have penetrated fissures in the latter while it was still hot, as the aplite is found in all sorts of small veins and masses which do not show any chilling along the contact. The rock is found frequently, but in relatively small masses. In the copper-bearing area the Modoc porphyry appears in lenticular dikes, traversing both varieties of granite in very irregular fissures. It is a light-colored rock, carrying large and distinct crystals of quartz in a dense groundmass, and is technically designated rhyolite-porphyry or quartz-porphyry. After the intrusion of the Modoc porphyry extensive fracturing occurred, with vein formation, the veins cutting the porphyry in many instances. After the formation of these earlier veins, renewed and very violent volcanic activity began, resulting in the intrusion and eruption of rhyolite, forming dikes cutting across the veins, and also great sheets and masses of fragmental material.

The Big Butte is formed of rhyolite, both fragmental and massive, and this rock occurs in dikes cutting both the granite and veins in the silver area, while the fragmental form covers a large extent of country west of the mines. These rocks are the product of volcanic action, and the Butte is the eroded remnant of a small volcano.

The granites are of Tertiary age, for at the borders of the batholith late Cretaceous strata are cut by the intrusion, and, moreover, included fragments of the early Tertiary andesites occur in the granite. The rock is cut by rhyolite dikes, and as rhyolite ash-showers form lake beds containing Miocene vertebrate remains, the granite and the veins are of earlier age, probably Eocene or early Tertiary. West of the district the lake beds appear, formed in a great Tertiary lake that filled a long and relatively narrow valley extending from south of Dillon in southern Montana to Garrison, a valley which was warped by later earth movements that drained it and carried the continental divide across its floor.

Structural Features. — The Butte Flat, a level valley bottom south of the city, contains no lake beds; it was formerly a normal erosion valley formed by the convergence of streams from east, west, and south of Butte,

[1] Called "granulite" by some writers — a name applied by German geologists to a variety of schist, but by French petrographers to aplite.

and was subsequently depressed by faulting along the base of the mountains east of Butte, which reversed its principal tributary and resulted in the filling of the valley by torrential débris and wash from the adjacent slopes. This faulting altered the ground-water level of the ore-bearing area and played an important part in concentrating the ores. The district is thus shown to be one of deep-seated igneous rocks, subjected to fracturing at various periods, the resulting fractures being in part filled by dikes, in part by veins, and in part displacing the veins; it is a region of continued and continuing crustal adjustment.

The veins occur in an area showing few outcrops, the rocks being altered by decomposition and disintegration and forming smooth slopes; only rarely do the granite boulders characteristic of the western part of the district show in the copper area. A few of the copper veins outcrop, but many of them, even the largest, are recognizable at the surface only by inconspicuous débris or do not show at all, a fact which has led to many lawsuits to determine ownership of orebodies.

The district embraces a well-defined area of copper lodes surrounded by silver veins with transition ores at the borders. Though the veins of these two areas present a strong contrast in mineralization and character, the vein systems appear to be similar, so that the area may be described as a whole.

The rocks of the entire district are traversed by a multiplicity of joints and fractures. These belong to three well-defined systems, as may be seen in excavations in the city, or, more clearly still, in the great boulder outcrops to the northeast, where the veins are seen to be merely mineralized joint fissures, the exceptional instances in which the fractures have been channels for mineralizing solution. In the copper area the rocks are intersected by a multitude of fissures, which near the surface are filled by quartz and iron oxide, with rotted or disintegrated granite between, soft enough to yield to the pick. In depth the lesser fractures are not filled and are therefore less conspicuous.

The veins of the district, both copper and silver veins, belong to three distinct systems. The oldest lodes have a general east-west course, the Parrot, Anaconda, and Syndicate lodes being examples. Another set of fractures has a northwest-southeast course, and has displaced the earlier veins. A still later set has a northeast course and has displaced both the earlier systems of veins. The first two systems are heavily mineralized; the last shows a li [illegible] ore, but the material mined is mainly the ore broken [illegible] included in the fault débris.

The silver veins surround the copper lodes on the north, west, and southwest. Their course and geologic relations are very similar to those of the copper veins, but their structure and mineralogic character are different. The silver veins contain sulphide of silver, blende, pyrite, and a little galena, and commonly contain no copper save near the border of the copper area, where, though occasional bunches of copper ore occur, it consists of chalcopyrite and more seldom still tetrahedrite, minerals which occur rarely and very sparingly in the copper lodes. The gangue consists of quartz with rhodonite and rhodochrosite, and shows marked banding and crustification, in strong contrast to the structure of the copper veins. These silver veins form very prominent outcrops, the quartz being stained black by manganese oxide. The veins are largely due to the filling of open fissures, and show but slight alteration of wall rock. They are displaced by and traversed by faults with friction breccias and alteration clays like those in the copper area.

The Copper Veins and Minerals. — Several of the copper veins were, as is well known, at first worked as silver veins. The upper portion of the veins consisted of quartz somewhat stained by iron, but not like the great iron gossan caps of other regions. This extends to a variable distance below the surface, 200 to 400 ft. in some instances, where it is replaced by partly oxidized and decomposed copper ores that form the upper limit of the remarkable glance, enargite, and bornite orebodies of the district. Carbonates and oxides are rare.

The copper minerals occur in quartz-pyrite veins of remarkable width and extent. The Anaconda ledge is frequently 100 ft. wide and will average half that width, as will also the Syndicate lode.

The copper minerals of the Butte ores consist chiefly of chalcocite (copper glance), bornite (peacock copper), enargite (sulpharsenide of copper), and cupriferous pyrite. Covellite (cupric sulphide) occurs in considerable amount in one or two mines, but forms an insignificant percentage of the total output. Tetrahedrite (gray copper) and chalcopyrite (copper pyrite) are even rarer than the last-named mineral. Until 1900 copper glance constituted the only important ore mineral of the veins, but it is now nearly equaled in quantity by enargite. In the great orebodies of the upper levels of the Anaconda veins glance occurred in masses of nearly pure lead-like mineral 20 ft. or more wide. In depth the mineral shows a more crystalline structure, and it is found in all the mines in greater or less abundance and purity, but in the great bulk of the ores it forms small grains scattered through the ores.

Bornite is less common than glance, and is practically restricted in [illegible] in the veins of the western part of the copper area. [illegible], [illegible] is [illegible] in great abundance, [illegible] the [illegible] of the [illegible] and [illegible] mines.

The gangue of all the veins is [illegible] quartz. [illegible] there is also a large amount of altered granite with [illegible] and [illegible] of ore. The [illegible] walls are often [illegible] by [illegible], but [illegible] prove almost [illegible] [illegible] to [illegible] post-mineral faulting. [illegible] frequently [illegible] a [illegible] of [illegible] [illegible] [illegible], a feature characteristic of replacement deposits.

Composition of the Ores. — The copper ores average [illegible] per cent silica and [illegible] per cent iron. About [illegible] per cent of the tonnage mined is first-class ore averaging [illegible] per cent copper; the remaining [illegible] per cent carries [illegible] per cent copper, and is treated in concentrating mills, the resulting product containing [illegible] to [illegible] per cent of silica, while the copper is increased to [illegible] per cent.

The ores contain gold to the extent of about [illegible]c. to each pound of copper, with 0.0375 oz. of silver. Native silver is of common occurrence in the ores, forming wire silver in bornite and glance and scales on joint planes. Gold has also been found upon crystallized glance, but with these exceptions no gold or silver minerals are recognizable in the copper ores. It is estimated that the total production of copper ore has been about 31,000,000 tons, averaging 5 per cent copper. The amount of arsenic present is very large, it being estimated that over [illegible] lb. a year pass off in smelter fumes. Tellurium is present in very small quantity in the ores, amounting to 2½ oz., or [illegible] per cent in the crude copper from the converters. It is recovered in electrolytic refining.

Ore Deposition. Three distinct periods of ore deposition are recognizable in the deposits of Butte. As many of the orebodies are of composite character and derive their contents in part from each one of these periods, a careful study is necessary to discriminate the evidence and results of each period. In general it is necessary to differentiate primary deposits, or those formed of material brought to and deposited in the veins from outside sources, and the so-called "secondary" deposits of transported and redeposited material. The former constitute the normal vein filling, the latter both the bodies of rich ore that have made the [illegible] [illegible] and masses of low grade, concentrating ores. As a general statement it may be said that the deposits of copper glance are [illegible].

The [illegible] [illegible] of the metallic contents of the primary deposits s still an unsolved question. To the writer the mineralogic evidence ind the intimate connection between periods of ore deposition and ig-ieous activity indicate a possible derivation from magmatic emanations – so-called mineralizing agents in waters partly of magmatic origin, ningled perhaps with predominating meteoric waters.

In general it may be stated that the original mineral-bearing solutions vere probably hot and ascended through fractures in the granite. The opper deposits are almost entirely replacement deposits formed by vaters ascending through mere cracks and attacking and replacing, article by particle, the adjacent rock. The silver veins, on the contrary, re in large part due to the filling of open fissures, though replacement eposits also occur. In the replacement deposits there is a general lack f definition between country rock and ore, a wide zone of altered de-omposed granite alongside of the vein, and commonly an impregnation f the rock between the individual veins of a lode with ore minerals. This s especially noticeable in the eastern part of the copper area, in Leonard, tarus, and adjacent mines. In the former an orebody is stoped out for 35 ft. in width, consisting of altered granite, sheeted and intersected y a multitude of small veins, crushed by later movements and replaced nd impregnated by pyrite, enargite, bornite, now in part replaced by econdary glance.

In the central part of the copper area fresh unaltered granite s uncommon. There has been local development of intense hermal activity. The rocks are closely fissured as a result of sev-ral periods of fracturing, and the mineralizing solutions have pene-rated and altered the rock between the fissures, converting and hanging the rock to what is conveniently called pyritized granite, ince the hornblende and mica are altered to pyrite and the feldspar o sericite and quartz.

The deep development work of many of the mines shows a decided hange in the amount of mineralization of the fractures. There is an ncreasing number of small veins of quartz and pyrite separated by al-ered granite. Some of the large lodes whose entire width is workable ass downward into a cluster of small veins of quartz and pyrite sepa-ated by altered granite. In other words, the replacement of inter-vein naterial by ore decreases with depth. There is also a decided increase n the number of small fissures devoid of ore and filled by friction breccia, ut showing trifling displacement. This is particularly noticeable in he levels 1600 ft. or more below the surface. On the other hand, some f the newer fault veins that show little or no ore in the upper levels

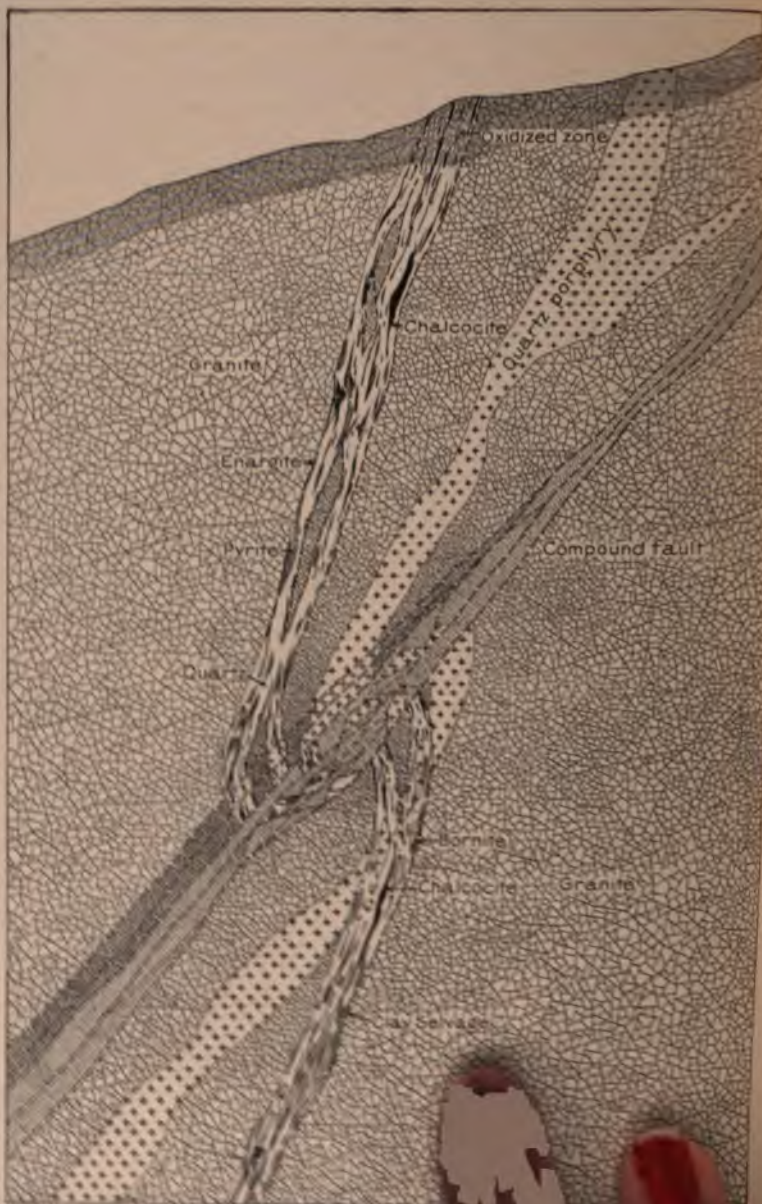


FIG. [illegible].—IDEAL SECTION OF BUTTE VEINS
PORPHYRY DIKES AND TYPICAL FAUL

contain pay ore below, because the open nature of the fault material permitted a deeper seepage than usual of descending waters.

Secondary Enrichment. — The enormous bodies of copper glance which have made the Butte district famous are probably the largest and best examples of secondary enrichment known. The fracturing of the veins has permitted the access of meteoric waters, which, dissolving the copper from the lean ores of the oxidized zone, deposit it, by reaction with pyrite, in the depths. These deposits were greatest in the upper level of the mines and have gradually lessened with depth. In some of the veins the lower limit of enrichment has been reached, in others the deepest workings still show these enrichments.

In general there is a marked association of faulting of the veins with bodies of rich ore, and these faulted areas are wet, so that the miners say: "A dry and tight vein is barren; a wet and crushed one is rich." This is particularly marked where the veins contain much pyrite. In the deeper levels newly deposited quartz occurs with the glance. In the deepest levels, 2000 ft. or more below the surface, rounded masses of glance 2 and 3 ft. across occur in crushed quartz containing relatively little pyrite. In the 2400-ft. level of the Anaconda group, a fine body of chalcocite is worked.

Change of Character of Mineralization with Depth.—The most notable change in mineralization with increasing depth is the greater abundance of enargite. In the eastern part of the copper area, in the Rarus Hill and its vicinity, this ore extends upward to the oxidized zone, sometimes very nearly to the surface. West of here there is a notable increase of enargite in depth, the mineral occurring for the first time in the very deep level of some mines (i.e. 1800 to 2200 ft.), an association that also prevails in some of the later veins, such as the Blue, as well as in the older ones.

Influence of Country Rock. — There is a distinct association of the copper deposits with the Modoc porphyry occurrence, since the most productive lodes occur in the area penetrated by this rock. The veins cross the porphyry, however, even the earliest ones, and hence the vein fractures are of later occurrence.

There is also a distinct genetic relation between ore and country rock, « a result of the deposition of the ore by metasomatic replacement. 'us the Anaconda ledge is low-grade where it crosses either the Bluebird ite (aplite) or the Modoc porphyry, a feature explainable by the)f easily replaceable, dark-colored, ferromagnesian minerals in those This feature is illustrated in figure 13.

The Vein Systems.—As a result of extensive development work necessitated by litigation involving ownership of orebodies, the evidence is now conclusive that the east-west veins have been faulted. The identity of the Original Parrot and Anaconda lodes is conclusively established, the displacement being due to the Blue vein. Farther east the Anaconda ledge is again thrown to the north by the Mountain View fault, the displaced segment forming the South ledge of the Mountain View mine, terminated eastward by the Rarus fault, throwing the lode southward, so that its eastward extension appears in the Rarus mine. The same faulting has displaced the other veins of this part of the district.

Earlier Veins, East-west System. — The great veins of the district, the Anaconda, Parrot, Mountain View, West Colusa, and Syndicate, belong to this east-west system, in which the trend is remarkably uniform, considering the length of the veins. The Silver Bow vein is a marked exception. There is some evidence to show that certain southeast fractures were mineralized in the earliest vein-forming period, and some of them reopened when the later faulting occurred.

These earlier east-west veins are distinguished as lodes or compound veins. They differ in structural and mineral character from the later lodes, and, except where faulted and enriched, lack the high silver contents of the veins formed later. Fortunately they have been extensively fractured by strike faults, as well as the two other vein systems noted.

Northwest Fault Veins. — The northwest system of fractures faulted and displaced the east-west veins. The three largest veins of this system, the Blue vein, Mountain View vein, and Grey Rock vein, are mineralized, but not so generally as the older veins; the ore occurs in chutes and is quite high grade and shows enrichment. The Blue vein has been developed for over a mile, and to a depth of 1000 ft., proving a heavy producer in several mines. It is cut and displaced by a northeast fracture in the Parrot workings.

Northeast Fault Veins. — The veins of both the east-west and the northwest systems are cut and displaced by those of the northeast system. The largest and best-known example of this is the Rarus fault, and the ownership of immensely valuable orebodies has hinged upon the geological conditions in the Rarus and adjoining claims. A careful and prolonged examination of all the accessible workings of these mines, including stopes, has resulted in the establishment of the following facts:

The Rarus faults have cut and displaced all of the veins. The cut-off is as sharp as if made by a knife, and the high-grade ore abuts against fault breccia. The veins displaced are so close together that on certain

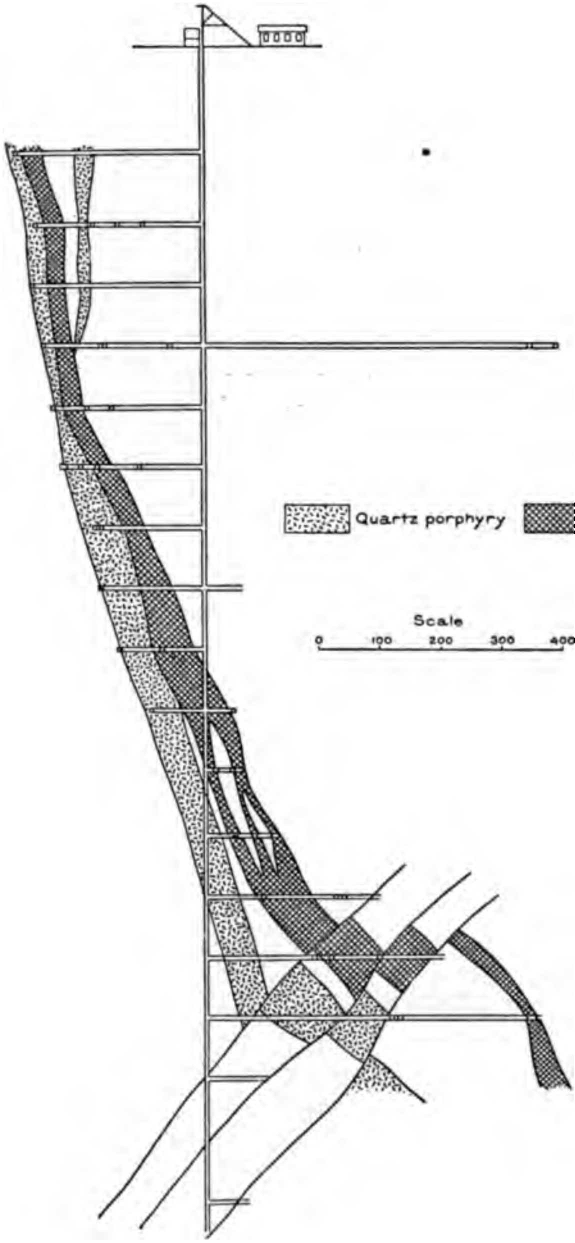


FIG. 141.—VERTICAL SECTION OF ANACONDA VEIN

levels the cut-off ends of different veins are opposite. The fault is compound, consisting of two fissures, the easterly with a dip of 45 deg., the westerly with a dip of 30 deg., and these fissures differ somewhat in strike. The interfault block is crushed, and the included vein segments are broken and their orientation is disturbed by a tilting of the block. The actual fault fissures are marked by attrition clay containing rock and mineral fragments. When indurated by infiltrating solutions, this resembles the quartz-porphyry. As the interfault material contains workable orebodies, stoping is sometimes continuous from one vein across the fault to another. Though legal opinions may differ, there is no geological continuity. There has been some ore deposited in the fault fissure, but not sufficient to form a new north-south vein along the fault, being confined to the proximity of older ore, upon and about which it was precipitated.

The Rarus fissure has now been developed to a depth of 1600 ft. and its existence established for a distance of 1¼ miles. Other fissures belonging to the Rarus system exist in many parts of the district, notably at the Original, Diamond, and Leonard mines, in which extensive mineralization has taken place.

Copper Deposits outside of the Butte District.—The copper deposits of the Blackfoot region, northern Front Range, and of the Belt ranges occur only where there are intrusive masses of diabase, and then only where this rock is much altered and decomposed. That the diabase is the source of the copper is probable; coming into solution in the hydro-metamorphism (alteration by atmospheric waters) of the diabase, it is precipitated in the clay shales by absorption, or by reduction due to organic matter. It impregnates shales, shaly limestone, and even some of the coral-like fossil remains. Where these Algonkian rocks are faulted and fissured, the copper occurs in the fault breccias, as at Coxcomb Butte, or in fissure veins, as at Copperopolis and along Sixteen Mile creek. The diabase masses are often very thick; a sill on the Blackfoot Canyon is 500 ft. thick, one on Sixteen Mile creek in Meagher county is 300 ft., and descending rain water has leached out the copper and carried it to lower levels, where it now occurs in the underlying calcareous shales.

A vein in Algonkian slates opened at Lenox, a suburb of Helena, Mont., showed copper pyrite and its alteration products, cementing a crushed mass of slate in a fault zone.

In the St. Mary's Lake region of northern Montana diabase dikes cutting across the range carry bunches of copper pyrite, etc., in the

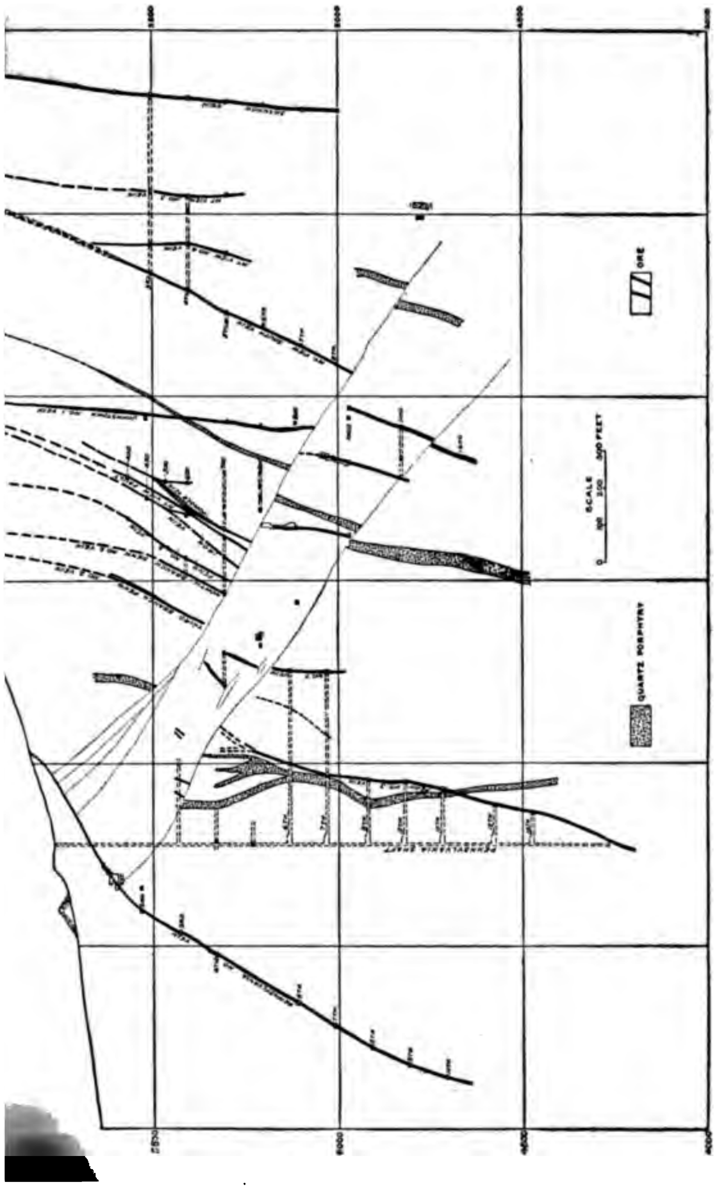


FIG. 142.—SECTION ACROSS VEINS OF PENNSYLVANIA, RARUS, MOUNTAIN VIEW, AND WEST COLUSA MINES, BUTTE, MONTANA

altered dike rock. Pyritic copper ores also occur in small deposits in the Judith mountains near Maiden. The Big Snowy mountains of central Montana contain undeveloped deposits of silver-rich copper ores in limestones overlying a laccolithic igneous core. Copper deposits are also known in the Sweet Grass hills.

South of Butte the Camp creek district contains deposits of small size in Archean schists.

The Castle mountain district at Copperopolis shows numerous quartz veins in gray slates of pre-Cambrian (Belt) age. The veins carry chalcopyrite and a little bornite near the surface, and in one mine a large body of glance was found at 600 ft. in depth, underlain by porous and vuggy limonite, the copper ore being evidently the result of secondary enrichment. This ore is now worked out and none of the other veins have proved workable, except the Copper Queen mine, near Castle, whose product was less than 100,000 lb. in 1905.

There are six silver-gold mines, yielding small amounts of copper as a by-product, scattered through this mountain region of the State, including the Atlas, near Wickes, Jefferson county, and the Boaz and Climax, near Norris, Madison county.

The Hecla Consolidated, near Glendale, was an important producer of lead-copper ores for twenty years, but is now worked out. The Cleve mine in this district is now a small producer.

The Indian Queen, near Apex, in Beaverhead county, is the largest single producer outside of the Butte district. The ore occurs in irregularly lenticular masses of chalcopyrite and pyrite, with glance, lying in fault clays along a movement plane between granite and limestone. The limestones show contact metamorphism, but the ores do not occur as a contact deposit, but are the result of hydrothermal action.

NEVADA

Nevada will doubtless in the near future be an important producer. The greatest deposits known in the State occur in the Ely region, 6 miles west of Ely, the seat of White Pine county, and connected by a branch line with the Southern Pacific Railway.

The Ely or Robinson mining district lies in a pass through the Egan range, a few miles to the southwest of Ely. The copper belt runs east-west, is about a mile wide and six miles long. The district shows Carboniferous limestones cut by an irregular intrusion of porphyry occupying the center of the belt. The main orebodies lie in

FIG. 143.—GEOLOGIC MAP OF ELY, NEVADA, SHOWING BOUNDARIES OF MINING PROPERTIES. (RALPH)

this porphyry. The oldest limestones belong to the Nevada limestone, 1000 ft. thick, overlain by the White Pine shale, also 1000 ft. thick, both formations being Devonian. This is overlain by the Carboniferous Ely limestone, 1500 ft. thick, capped by the Arcturus, 1000 ft., overlain by the Ruth limestone. See Fig. 143.

A body of intrusive granite, a coarse-grained pink to gray hornblende-monzonite, cuts the upturned sedimentary rocks and has produced a limited alteration of the adjacent limestone to garnet rock holding some chalcopyrite, but no important deposits of this nature have yet been found. Dikes of coarse monzonite porphyry also occur, but are of no significance economically. The latest rocks are rhyolite lavas, both pitchstones and tuffs. This rhyolite has been faulted with all the older rocks. See Fig. 144.

The copper-bearing porphyry is a light yellowish or whitish feldspathic rock with a prevalent porphyritic structure. It covers two areas: the first from Copper Flat 3 miles west to Rusty Ridge, and a width of five-sixths of a mile. The second area is 3 miles long and three-fifths of a mile wide, extending eastward from Ocher Valley. The rock shows every gradation from an altered holocrystalline rhyolite porphyry rich in orthoclase but altered by hot carbonated sulphurous waters, to a bleached pyrite-bearing rock, and this to an end product of cellular secondary quartz. In general it is "a very much kaolinized, silicified, carbonated and pyritized rhyolite."[1]

The great payable orebodies of the district are parts of the porphyry mass, mineralized by pyrite and copper glance. The outcrop is yellowish or less commonly red, and almost devoid of copper. There is an abrupt change from this to the unoxidized bluish white rock well sprinkled with minute crystals of pyrite and copper glance. The lower limit of oxidation is about 100 to 150 ft., is very irregular, and has no relation to the ground-water level. The mine waters carry 9.36 grains per gallon of ferrous sulphate, with but 0.4 grains per gallon of ferric sulphate.

The pay ore lies under the zone of oxidation and is about 400 ft. thick. The copper values are not uniformly distributed, and the richer ground appears controlled by local conditions permitting the free descent of surface waters. According to Lawson, the workable orebodies are

[1] Andrew C. Lawson, "The Copper Deposits of the Robinson Mining District, Nevada," *Bulletin* Geological Department, University of California, 1906, vol. iv, pp. 287-357. The map and section given in Figs. 143, 144 are from mining conditions at Ely, Nev., by E. W. Ralph, Mining and Scientific Press, vol. xciv, 1907, p. 120.

tertiary, not secondary, and result from the leaching of the former secondary ores of the oxidized zone. The only primary ores occur as chalcopyrite in garnet rock in or beneath quartz blowouts (blouts).

An average of 1000 samples of ore from the Ruth mine yielded 10 per cent pyrite and 3.25 per cent chalcocite, equal to 2.61 per cent copper, 6 per cent iron, and 5.34 per cent sulphur. There are considerable parts of the orebodies which carry 8 to 10 per cent copper.

The most notable feature of the porphyry ores is the occurrence of large bodies of quartz commonly known as blowouts among prospectors, and called "blouts" by Professor Lawson. These quartz masses are of large size and irregular outline, and cover nearly one-third of the porphyry area. Most of this quartz occurs on the border of the porphyry mass, between it and the limestone, and the masses in the central part of the porphyry area appear to be caps on hilltops and ridges. If the porphyry mass itself is laccolithic and was formerly covered by limestone, these central blouts are also at the limestone-porphyry contact.

This blout shell about the porphyry was of variable thickness and not continuous. It is not, as commonly supposed, the outcrop of an orebody, but the result of replacement of limestone and in part of a silicification of the porphyry. The blout does not go down, but is often underlain by lean copper-bearing garnet rock.

The presence of a dike of corundum-bearing minette northeast of the mine workings may have been due to interrupted circulation and affected enrichment.

At Copper Flat the porphyry ore differs from that of the Ruth mine in an important particular, i.e. in the zone of oxidation the copper has not been leached out, but remains in the form of carbonates. In the unoxidized zone beneath the ore is like that of the Ruth save that it holds nests of bronze or brown mica, where the ore is richest.

The porphyry ore of Ely, like that of Cananea, is intensely internally deformed. Although the ore-bearing porphyry occurs in small and definitely limited masses "in the midst of unaffected or but gently folded and broadly faulted" rocks, it shows slips, faults, slickensides, and bands of black gouge, all closely spaced and evidencing repeated and complex faulting, a result of an adjustment of the mass, due to shrinkage of volume resulting from chemical alteration with coincident sericitization and koalinization by the action of carbonated waters. Lawson assumes these waters to be carbonated by carbon dioxide given off by the limestone when in contact with the hot intrusive mass, and the slipping and shearing to show a progressive, long-continued alteration in which the porphyry was leached of copper and silver, forming blouts containing chalcopyrite. This in turn was altered by surface waters, leached and glance formed below.

The orebodies are of enormous extent. That of the Eureka mine is 700 by 800 ft. and has been developed to a depth of 100 ft. That of the Ruth mine has a width of 50 to 250 ft., is developed for 400 to 900 ft. in length, and has a known vertical thickness of 250 ft. According to Channing, from whose report upon the Nevada Consolidated Copper Mining Company these notes are taken, the rock is leached for 50 to 100 ft. down, carrying not over ½ per cent copper. Below this the ore is white and soft, and consists of decomposed porphyry, carrying minute seams of pyrite and copper glance, with some quartz. This is a typical disseminated ore, exactly analogous to the ores of Morenci and Bingham. At the Ruth mine there is a 640-ft. inclined shaft, having an angle of 41 deg., equal to 420 ft. vertical. The orebodies are become low-grade at a depth of 400 ft., the approximate limit of secondary enrichment. The ore has an average value of 2.2 per cent copper at the Eureka mine, with 40c. per ton in gold. It is expected that a saving will be made of 77 to 79 per cent of the copper content of the ore. These properties are in the eastern or central portion of the belt. The western portion of the quartz-monzonite area is owned by the Giroux Copper Mining Company.

The Sodaville copper belt occurs in Esmeralda county, at the north end of the Pilot mountains, some 18 miles east of Mina, a new town on the Carson & Colorado Railroad. The copper ores occur in a contact zone 12 miles long, on the borders of a granite intrusion. The Copper Mountain or Tecoma mines are also in the Pilot range, but in Utah.

New Mexico

Copper ores are widely distributed throughout New Mexico, but there are few producing mines. The Santa Rita mines, the Mogollon district, the newly discovered Burro mountain (Grant county) mines, and the lesser properties of the Organ mountains and of San Miguel county complete the list.

There are many pre-Cambrian copper deposits consisting of chalcopyrite and zinc-blende inclosed in schistose amphibolites. Examples occur at the Hamilton mines, on the upper Pecos, 20 miles east of Santa Fé, and along the Santa Fé range northward (Frazer Mountain

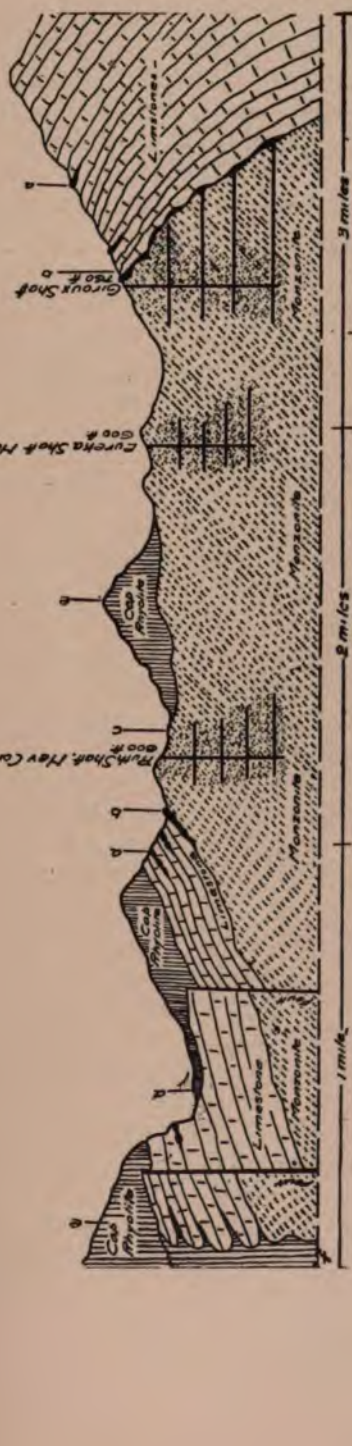


FIG. 144.—LONGITUDINAL SECTION OF THE ELY DISTRICT SHOWING PRINCIPAL SHAFTS. (RALPH)

Copper Company, near Taos), while the deposits of the Hopewell and Bromide districts in Rio Arriba county are narrow stringer veins in altered amphibolites. Post-Cretaceous copper deposits are more abundant. They are either contact metamorphic replacements of limestone and associated veins about great intrusive bodies of acidic porphyrites

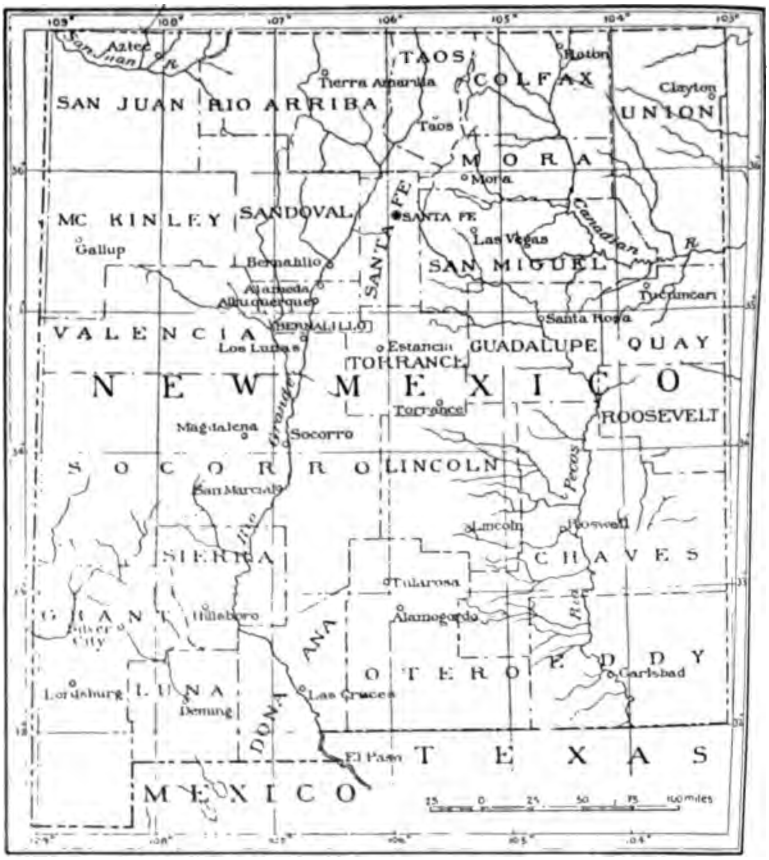


FIG. 145 INDEX MAP OF NEW MEXICO

and granitic rocks, or are fissure veins cutting Te c lav
Copper also occurs as widely distributed through the rocks
New Mexico, as of Texas, Arizona, and Utah. Co
about the Ortez and San Pe ntains, at Cim
where (in Colfax county), at nta Fé cou

county), near Hachita in southern Grant county (Copper Dick mine), and Santa Rita, Hanover, and Fierro (Grant county), and Pinos Altos, north of Silver City.

The Burro Mountains deposits show narrow veinlets of cupriferous pyrites in porphyry, and associated disseminated deposits of copper glance.

The Cooney district lies on the west side of the Mogollon mountains, in the southwest corner of Socorro county, at an altitude of 6500 ft., while the neighboring peaks reach 12,000 to 13,000 ft. above the sea-level. The district is one of igneous rocks, chiefly dacitic and rhyolitic lavas cut by rhyolite dikes. The copper ores occur in brecciated fissures in volcanic lava flow rocks, mostly on the dike contacts, but true fissure deposits also occur. The district has produced about $7,850,000.[1]

The Cooney vein, worked by the Mogollon Gold and Copper Company, runs northwest and southeast, and is a brecciated fissure deposit of large size. Below water level the ore is bornite and copper glance carrying silver, in a gangue of quartz, fluorite, and calcite formed as a replacement in the trachyte changing wall along a rhyolite dike. The ore occurs in shoots, and in the oxidized zone it was rich in gold.[2]

The copper-lead-zinc deposits of the Magdalena range are contact metamorphic replacements in a westward-dipping limestone bed on the west side of the range, occurring near the monzonite contact.

Donna Ana county contains copper mines in the Organ district, in which the Torpedo, Memphis, Copper Bar, Excelsior, and other properties occur along a contact between altered limestone and igneous rocks, the conditions being somewhat similar to those observed at Clifton, Ariz. The copper occurs in the central portion of the contact, where the limestone has been converted into garnet, vesuvianite, and epidote.

The Silver City district, in which the Comanche Mining and Smelting Company is situated, furnishes the main output of the territory. This company owns the Hearst mine, which works a body of low-grade sulphide copper ore developed to a depth of 800 ft. The ore is, however, refractory and contains a large amount of zinc.

Otero county yields a small production from the mines in the Jarilla mountains. Luna county contains the Apache mine near Hachita,

[1] Blakely Graham, *Engineering and Mining Journal*, Oct. 20, 1906.

[2] W. Lindgren and L. C. Graton, "Mineral Deposits of New Mexico," *Bulletin* 285, United States Geological Survey, p. 85.

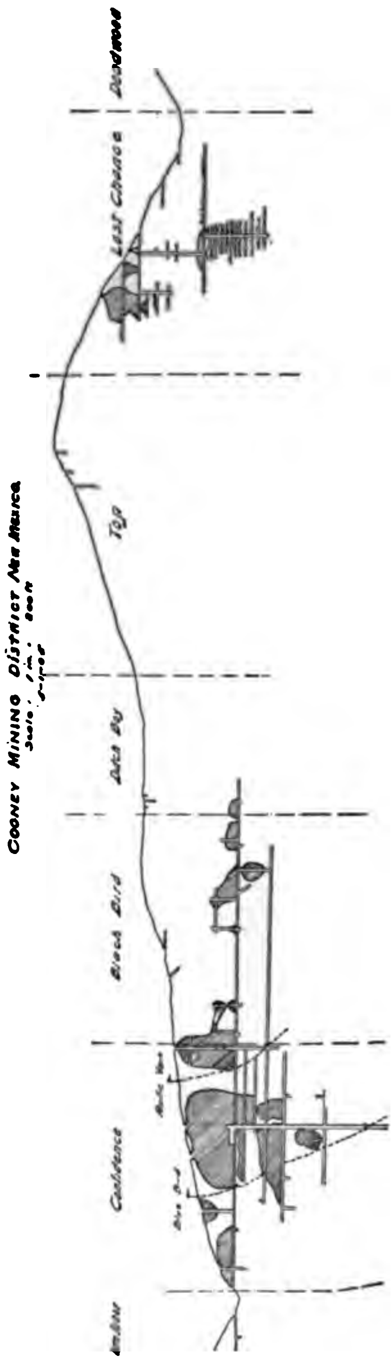


FIG. 146. - SECTION ACROSS THE OREBODIES OF THE COONEY DISTRICT, NEW MEXICO

which is a small producer. Sierra county contains a few small copper mines near Hillsboro. Socorro county's copper production comes from the mixed sulphide ores of the Magdalena mountains. Taos county has an insignificant production from small streaks of chalcopyrite in schist. Sandoval county contains the Nacimiento district, where the ore occurs as fossil palm leaves and tree trunks, consisting of copper glance occurring in Triassic sandstones. The deposits are not worked.

The Santa Rita property is said to show an underlying core of igneous rock, with an overlying bed of quartzite about 50 ft. thick, which is impregnated with native and oxide ores. The quartzite lies at a gentle angle, and is overlain at some distance from the mines proper by an altered limestone, which has presumably been eroded off in the vicinity of the mines, and during this erosion has furnished the solutions for the impregnation of the quartzite. Sulphide ores also occur in the underlying porphyry, extending downward as deep as the workings have been carried, some 300 ft. below the surface.

The Red Bed area of New Mexico covers a considerable portion of the territory and contains extensive deposits of oxidized ore.

About 40 miles east of the Rio Grande Valley, in New Mexico, is a disconnected series of mountain ranges along a common line of uplift, known in various parts, proceeding from south to north, as the Franklin range, San Andreas mountains, Sierra Oscura, and the Sandia mountains.

The deposits in the Sierra Oscura occur along the east flanks of the range, in Red Beds which lie between Carboniferous limestones below and red sandstones and shales above, the latter being thought by Turner[1] to resemble the Permian of western Texas. These beds dip eastward, away from the granite core of the range. The copper ores occur in beds of arkose sandstone and of shale, two ore-bearing horizons being recognized in the former. The ore consists mainly of glance and carbonate in minute grains disseminated through the rock; also, especially in the shales, in nodules which often have a kernel of sulphide, chalcopyrite, bornite, or chalcocite; likewise replacing plant remains. The arkose sandstones contain rolled grains of iron oxide, in part magnetic. Deposits of chalcopyrite are found on certain fault fissures cutting the beds, but Turner thinks the ores were deposited prior to the main faulting of the region, and that the copper was precipitated from the waters in which the inclosing sediments were laid down.

In the San Andreas mountains the abrupt escarpments, due to fault-

[1] H. W. Turner, *Engineering and Mining Journal*, vol. xxxiv, p. 270.

ing on the east side of the range, afford frequent and good exposures. The Carboniferous limestones rest on granite and are cut at intervals of half a mile or more by a series of vertical veins from 5 to 20 ft. thick. These veins, which carry various metallic minerals in a gangue of quartz, fluorspar, calcite, siderite, or barite, can be traced to the contact with the granite, but do not appear to have entered the latter rock. There is a thin band of red sandstone at the contact, in which has accumulated a bed of hematite carrying copper ores consisting of glance, malachite, cuprite, etc. The copper does not occur to any considerable extent in the limestone above or the granite below. Without explicitly stating his reasons, C. L. Herrick[1] assumes that the iron ores in this band have leached down from above, but that the copper came up from the depths.

OREGON

The northern extension of the copper belt of California passes into Josephine county, Oregon. The Takilma Smelting Company, near Waldo, began operations in 1904. In that year there were four copper-

FIG. 14[illegible]. INDEX MAP SHOWING COPPER PROPERTIES OF OREGON

producing counties in the State, but of the aggregate of 269,510 lb. all but [illegible] lb. came from this smelter. So far as information is

[1] C. L. Herrick, *American Geologist*, vol. xxii, pp. 285–291.

available, the orebodies of this region consist of chalcopyrite ores with a little bornite in a gangue of pyrite and pyrrhotite. They form lenticular masses inclosed in altered and schistose igneous rocks, but as the locality has not been studied, no detailed information is available.

In eastern Oregon there are a number of copper properties, which have attracted more or less attention for some years past. They occur in the Blue mountain region, and most of the deposits are contained in Triassic lavas, mainly basaltic, with ore interbedded with sedimentary rocks of the same age. Three types have been distinguished by Lindgren:[1] the Seven Devils type, the Tourmaline type, and the Snake River type. The first named includes contact deposits of irregular bodies of chalcopyrite and bornite, lying between limestone and diorite. The ores contain a gangue of garnet, epidote, and other contact minerals. The only example of this type occurs near Medical Springs.

The Tourmaline type is characterized by chalcopyrite and pyrite associated with a gangue of quartz and tourmaline, the ores occurring in fissure veins and irregular replacements. The Copperopolis mine, in the Quartzburg district, and the Jessie vein, in the Mineral district, are of this character.

The Snake River deposits occur in the canyon of that stream, southwest of Seven Devils, 80 miles from Baker City. The deposits are largely of metasomatic origin and consist of finely distributed copper glance, bornite, and rarely of chalcopyrite, in Triassic lavas or tuffs. The distribution of the sulphides is irregular, but commonly follows well-defined directions, probably determined by joint systems, though no sharply defined fissures could be observed. The gangue minerals are quartz, epidote, actinolite, or chlorite. At Copper Union and near Ballards Ferry, in the Snake River Canyon, the deposits are epidotic. In the Snowstorm mine, near Sanger, the rock is a diabase and the ore actinolitic. The Iron Dike and River Queen deposits are chloritic.

The Copper Butte district contains a number of deposits in basaltic rocks of Triassic age.

Among the copper deposits noted in the foregoing paragraphs there are no producing mines, though small shipments of high-grade ores have been made from one or two of the prospects. In general it may be said that the ores are low-grade, and that the zones will not average more than 1 or 2 per cent copper.

[1] "Geology and Ore Deposits of the Blue Mountains of Oregon," *Annual Report* of Director, United States Geological Survey, 1901.

TENNESSEE

The copper production of Tennessee comes entirely from the Ducktown district. The production is about 1,000,000 lb. of copper per month, the recovery in 1905 being 35 lb. of copper per ton of ore.

Geology. — The district is in the extreme southeast corner of the State, on one of the lines of the Louisville & Nashville Railroad. The deposits outcrop on a small upland plateau inclosed by higher mountains and trenched by stream channels. The country rock is a thinly foliated mica schist with occasional intercalated layers of gneiss.

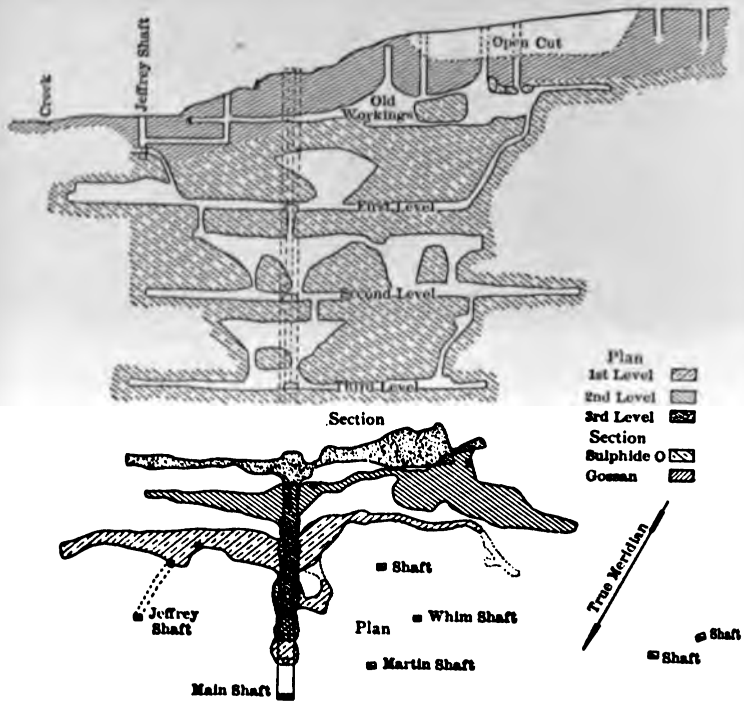


FIG. 148 — SECTION, AND MAP OF LONDON MINE, DUCKTOWN, TENN.

The Ducktown property is probably on an anticlinal axis, and may be along a fault zone. The rocks are presumably Ocoee (Lower Cambrian), and are more metamorphosed than the members of the series seen to the southwest, but not so much altered as the granite-like rocks of the same series seen to the northeast. In the Hiwassee Canyon the sandstones may be seen to shade into metamorphic mica-quartz gneiss, and the interbedded clayey beds to change to a soft schist. The foliation runs north-northeast, and the beds dip at 50 deg. to the southeast. Microscopic study by Kemp [1] shows the rocks to consist of biotite and quartz, evidencing a sedimentary origin.

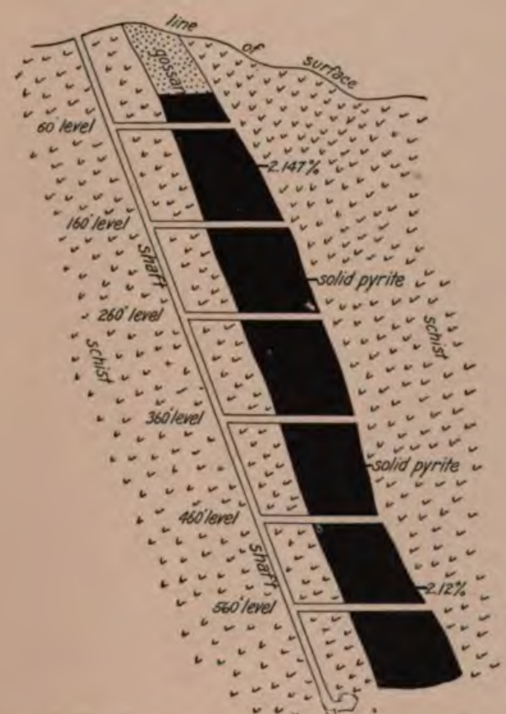


FIG. 149.—VERTICAL SECTION OF OREBODY, LONDON MINE, DUCKTOWN, TENN.

The ore consists of massive pyrrhotite, containing interspersed particles and stringers of chalcopyrite and pyrite, together with minute quantities of galena and zinc. Calcite, zoisite, quartz, and occasional bunches of garnet occur, and in some deposits actinolite occurs. The copper content averages about 2 per cent.

The deposits consist of long and exceptionally thick masses of solid ore, containing a few included slivers or horses of country rock and sur-

[1] *Transactions* American Institute of Mining Engineers, vol. xxxi, 1901, p. 224.

rounded by low-grade hornblendic ore. The deposits occur on three lines of fracturing and probable faulting and rock crushing. They are classed as replacement veins, similar to Ore Knob, N.C., and the Gossan Lead of southwest Virginia, but the orebodies are larger. Diagonal faulting of the orebodies has occurred.[1]

The London and Burra Burra mines are on the westernmost vein, the Isabella on the middle, and the Polk county, Mary, and Calloway mines on the southeast vein of the district. The Tennessee vein lies west of the last mentioned, and there are two smaller intermediate orebodies.

The deposits are extensively worked by two companies, the Ducktown Sulphur Copper and Iron Company, and the Tennessee Copper Company. The Burra Burra mine of the latter company is now 560 ft. deep, the orebody maintaining its nearly uniform dip (of 60 deg.) and thickness to the lowest workings.

The ore of the different mines has the following composition[2]:

TABLE SHOWING COMPOSITION OF DUCKTOWN ORES

Copper	2.744	2.79	2.2	3.0
Iron	36.519	43.26	37.5	31.0
Sulphur	24.848	29.18	30.0	21.0
Silica	18.548	10.01	10.3	26.3
Lime	7.294	6.32	6.2	6.1
Magnesia	2.672	1.39	1.9	2.5
Zinc	2.556	2.56	2.0	0.8
Alumina	0.911	1.00	3.9	4.4
Manganese	0.770	0.69		
[1] Carbon dioxide	3.138	2.80		
	100.000	100.00		

[1] By difference.

The first two columns represent the composition of the ores smelted by the Ducktown Copper Sulphur and Iron Company; the third and fourth columns the ores of the Burra Burra and London mines respectively, both being from the same vein. It will be seen that there is considerable difference in the composition of the different ores from the different parts of the same orebody.

The Burra Burra ore carries 2.3 per cent copper, 0.33 oz. silver,

[1] Carl Henrich, *Transactions* American Institute of Mining Engineers, vol. xxv, 1895, p. 198.

[2] J. Parke Channing, "Pyrite Smelting," p. 254; W. H. Freeland, "Pyrite Smelting," p. 111.

0.001 oz. gold, and 0.01 per cent TeSe per ton. It is concentrated 50 to 1 by matting, the pig copper carrying 99.4 per cent copper, 12.5 oz. silver, 0.025 oz. gold, 0.01 per cent tellurium and selenium, and 0.0007 per cent arsenic.

The Ducktown ores are smelted raw, in blast furnaces, with a concentration of about 7.3 into 1, forming a 12 to 20 per cent matte, which is resmelted with a small amount of raw ore, quartz, etc., and raised to a 50 per cent matte, which is in turn bessemerized.

The Tennessee company is erecting an acid plant to make low-grade sulphuric acid out of the fumes from the blast furnaces.

Utah

The copper production of Utah for 1906 is estimated at 56,800,000 lb.[1] This output comes mainly from the copper mines of Bingham, Mercur, Tintic, and Park City.

The Bingham camp has been successfully developed until it is now one of the greatest copper camps of the country. In addition to the production from the well-known flat orebodies in the limestone, the copper-bearing monzonite ores have been proved to be of great economic value.

Copper Deposits of Bingham.[2] — Bingham is the leading copper-producing camp in Utah. The present output is composed almost entirely of low-grade pyritous copper-sulphide ore, with comparatively small amounts of enriched high-grade black copper-sulphide ore and of rich argentiferous lead ore. The annual output, as reported for 1904, is nearly a million tons of ore. The total output, 1870–1904 inclusive, is valued at $40,000,000.

This district is situated in the north-central part of Utah, on the rugged eastern slopes of the Oquirrh mountains, 20 miles southwest of Salt Lake City. The productive region proper, occupied by about 125 properties, embraces an area of about 15 square miles, but the five great properties which produce the bulk of the present output lie within a single square mile.

The product is supplied by a few large consolidated properties, including the Utah Consolidated Company, operating the Highland Boy mine; the United States Mining Company, operating the Old Telegraph and Old Jordan mines; the Bingham Gold and Copper Company,

[1] *Engineering and Mining Journal*, January 5, 1907.
[2] J. M. Boutwell, *Engineering and Mining Journal*, June 22, 1905.

operating the Commercial, Dalton-Lark, and Brooklyn mines; the Boston Consolidated Company, operating the Old Stewart mine; the Yampa Consolidated, working the Yampa mine; and the Utah Copper Company, operating the Wall property.

Underground development, though extensive, is shallow. Sinking has proceeded below the level of surface-water in only three or four properties. As development work has never been carried deep, the persistence of pay ore to great depth has not yet been demonstrated.

FIG. 190.—HIGHLAND BOY MINE, BINGHAM, UTAH

Geology. — This region has been the center of a complex succession of activities which culminated in ore deposition. In brief, sedimentary country rock, which consists of Carboniferous quartzite, including limestone and calcareous shale, has suffered extensive intrusion, thorough contact metamorphism, intense fissuring, and partial burial beneath a latite flow. The sedimentary section embraces s thousand feet of massive quartzite, with a few relatively thin be estone intercalated in the lower half, and black calcareous ous sandstones, and impure limestones in the uppe ssil these intercalated members prove the age of the boniferous. The limestones of the lower portion, averaging 200 ft. thick, have been highly marbleized and form the country rock for large bodies of copper ore. The calcareous carbonaceous shales of the upper part, sometimes several hundred feet thick, also favor ore deposition. In general, the sediments throughout this region dip northward and strike northeast and southwest. This strike is not constant, however, but turns gradually from an east-west course on the western slope of the range to a north-south trend on the eastern. The area occupied by this district thus lies in a shallow flaring trough or synclinal basin that pitches northward.

This general succession and structure has been interrupted, particularly in the geologically lower portion, by many irregular dikes and sills of monzonite porphyry, by laccolithic masses of monzonite, and by several systems of persistent fissures. Two extensive areas of monzonite occur in the center of the camp, one in the form of an irregular laccolith, the other in the form of a broad, irregular stock. The porphyry dikes and sills adjoin these masses on the east and west. An extensive body of latite, outcropping along the eastern slope of the range, is a flow which buries an old topography carved in the sediments, and probably also in the intrusives.

After the epoch of igneous intrusion, intense fracturing and fissuring occurred throughout the district at several periods. Dominant fissures and fracture zones, which include the principal bodies of lead and silver ore, trend northeast and southwest; distinctly later ones, which fault the ore, trend northwest and southeast. Numerous minor fissures follow intermediate courses, and movement has recurred in a northeast-southwest direction. The displacements produced are frequently of a complex nature, but rarely exceed 150 ft., and are usually considerably less.

Occurrence of the Ore. — The productive area is limited to a region characterized by intrusives. Within this area the largest orebodies occur in metamorphosed limestone adjacent to intrusives and to fissures. Outside of this comparatively small area orebodies have not been found.

The copper ore occurs in large masses in limestone and also in minute grains disseminated through monzonite. The large bodies lie within massive marbleized limestone adjacent to intrusives and to fissures. They are in the form of beds, lying roughly parallel with the bedding the country rock, and exhibit a massive banded structure. These irlar beds of ore are localized into elongated lenticular shoots, which ughly with the bedding and pitch moderately. The shoots somessume great size, being several hundred feet along their strike, nearly 200 ft. thick, and have been followed downward continuously for several hundred feet.

The large ore-shoots which have been opened in Highland Boy ground, through a series of seven strike-adits, are excellent examples of this class of deposits. The No. 1 shoot in this mine is not only the largest orebody known in Bingham, but it is one of, if not the largest, in the world proved to have been formed by replacement. Other valuable bodies which exhibit the same general characteristics have been developed in the Telegraph, Old Jordan, Commercial, Boston Consolidated, and Yampa mines.

The copper ore which occurs in intrusives is disseminated throughout a large laccolith or monzonite, especially in those areas in which the country rock is fractured, fissured, and altered. Of the fissures observed, over 84 per cent trend northeast-southwest, and over 90 per cent dip to the northwest. The Galena fissure, which has been more extensively opened than any other, is known for about 3500 ft. horizontally and about 700 ft. in depth. The Eagle Bird fissure in Butterfield ground has been followed continuously downward on a steep dip about 800 ft. Among the veins which have yielded a valuable output are the Winamuck, Robbie, Silver Shield, Nast, Last Chance, Erie, and Montezuma.

Character of the Ore. — Nearly all of the present output is derived from the bedded ore in limestone. This is made up of copper sulphide ore, in which the primary sulphides, massive chalcopyrite and pyrite predominate. Those portions which have been most exposed to superficial alteration, however, afford enriched sulphide ore containing chalcocite, tetrahedrite, and tenorite. Tellurium is sometimes associated with the black sulphide, with increased value in gold and silver. Quartz is the principal gangue material of the sulphide copper ore, and garnet, epidote, tremolite, specularite, pyrrhotite, sphalerite, etc., are associated in small amounts.

The copper content in the average sulphide ore is low, ranging from 2.5 to 5 per cent, with an approximate mean of 3.5 to 4 per cent. The accessory gold, averaging from 10c. to $1 per ton, and silver averaging from 2 to 5 oz. per ton, raise the total value of this ore to a price ranging from $11 to $15 per ton. The average content of the fissure ores is approximately 45 per cent lead, 65 oz. silver, small amounts of gold and copper and zinc. Accessory gold, probably in pyrite, ranges in the copper ores in limestone from 80c. to $2.20, in lode ores 50c. to $2.50, and in the milling ores from monzonite it averages about 30c. per ton. Zinc-blende is a constant associate in the lode ores. It ranges from a trace to 45 per cent, and averages 10 to 15 per cent.

Genesis of the Ore. — In Mesozoic or early Tertiary time intrusive odies of monzonite invaded a mass of quartzites and limestones, proucing contact metamorphism, with the intrusion of pyritous copper ılphides as replacement of marmorized limestone. After the cooling f the upper part of the intrusive monzonite to at least partial rigidity, and the inclosing sedimentary rocks were fractured by persistent orthwest-southeast fissures. Heated aqueous solutions from the eeper unconsolidated portions of the magma ascended through these ssures, altering the fissure walls, introduced additional metallic ma:rial, adding to the deposits in the limestones, altering the monzonite, nd adding copper, gold, and silver as auriferous chalcopyrite, pyrite, nd molybdenite to the monzonite. Two periods of mineralization are learly defined: first, that of contact metamorphism, with intergrowth f ore, garnet, etc., second, after actions, producing the disseminated res and the lodes.

The site of the orebodies was determined by selective preference of nineral solutions for deposition in certain beds, a preference quite as narked with different limestone beds as it is between limestone and uartzite.[1] The disseminated ores[2] were deposited by hydrothermal ction subsequent to the date of the igneous intrusion, and the sulphides re now undergoing normal superficial alteration. The ores occur in he joints of the rock as a mossy coating of quartz and sulphides, but lso in the body of the rock, especially associated with dark ores of ferroagnesian minerals, principally secondary (?) biotite. The productive round is coextensive with monzonite exposures, as may be seen by omparison of the geologic and economic maps. All the monzonite was, owever, not mineralized, and it was only where extensive fracturing peritted the access of the deep-seated solutions that mineralization was xtensive enough to form workable ore deposits. In the Utah comany's claims an average assay of 6000 samples corresponds closely to he grade of ore now milled, showing 1.98 per cent copper, 0.016 oz. er ton gold, and 0.15 oz. per ton silver.

The *Newhouse* or *Cactus* mine in Beaver county is now one of the egular producers of the State.[3] The mine is 4½ miles northwest of Frisco, in the San Francisco mountains, and is reached by a branch line of the Los Angeles Railroad. The ore consists of coarsely crystalline

[1] Boutwell, "Geology of the Bingham, Utah, Mining District," *Professional Paper* No. 38, p. 128, United States Geological Survey.

[2] *Ibid.*, p. 172.

[3] S. F. Emmons, in *Bulletin* 260, United States Geological Survey, p. 242.

pyrite, with a little chalcopyrite and rarely a little sooty chalcocite. The deposit is a shear or crush zone in monzonite, 15 to 30 ft. wide, the ore cementing fragments and filling cracks and crevices in the shattered rock. The ore zone is vertical, and is developed to a depth of 600 ft. by a shaft and a cross-cut tunnel over a mile long. While the mine yields some smelting ore, the main product is concentrating ore treated in an 800-ton mill and concentrated 6 into 1. The shear zone is a strong fault zone, traceable for a mile or more across the mountain slopes running toward the Horn Silver fault. The 400-ft. level shows the ore zone to be 710 ft. wide and on the 500-ft. level the orebody is 225 ft. wide. The output in September, 1906, was about 900 tons of 2.75 per cent ore per day.

Park City district, though better known as a producer of argentiferous lead ores, yields an important and increasing output of copper ore. Copper is commonly present as tetrahedrite (gray copper) or fahlore in the high-grade silver ores, the average copper content of such ores being about 2.5 per cent copper, 40 per cent lead, and 60 oz. silver per ton, while the crude ore sent to the concentrators carries 1.5 per cent copper.

The ore occurs in fissure lodes and as masses in limestone, the bulk of the ore now extracted coming from the bedded orebodies in limestone. The northeast-southwest fissures, with steep northwest dip, are wide and persistent veins, 2 ft. to 35 ft. wide, carrying narrow pay streaks of high-grade ore.

The "bedded" deposits are replacements of and occur in certain layers in upper Carboniferous and Permian limestones, the ore-bearing layers being inclosed in quartzite. Both lodes and replacement bodies occur intimately associated with porphyry intrusions.

Development of these orebodies has been very extensive, it being possible to walk for nearly 5 miles in one general direction underground, and the Ontario shaft is 2000 ft. deep.

The Ontario, Daly West, Daly Judge, and Silver King are the largest companies.

Tintic District. — The orebodies occur on the western slopes of the Tintic range, Eureka and Mammoth being the chief towns.

Geology. — The ore-bearing district consists of folded Carboniferous limestones, adjacent to a granitic (Sunbeam monzonite) intrusion on the south, with quartzite forming the mountain flank on the west and an extensive area of rhyolite on the east.

Ore Deposits. — The ore deposits occur in sedimentary rocks, in igneous rocks, and as contact depoits. There are three ore zones in

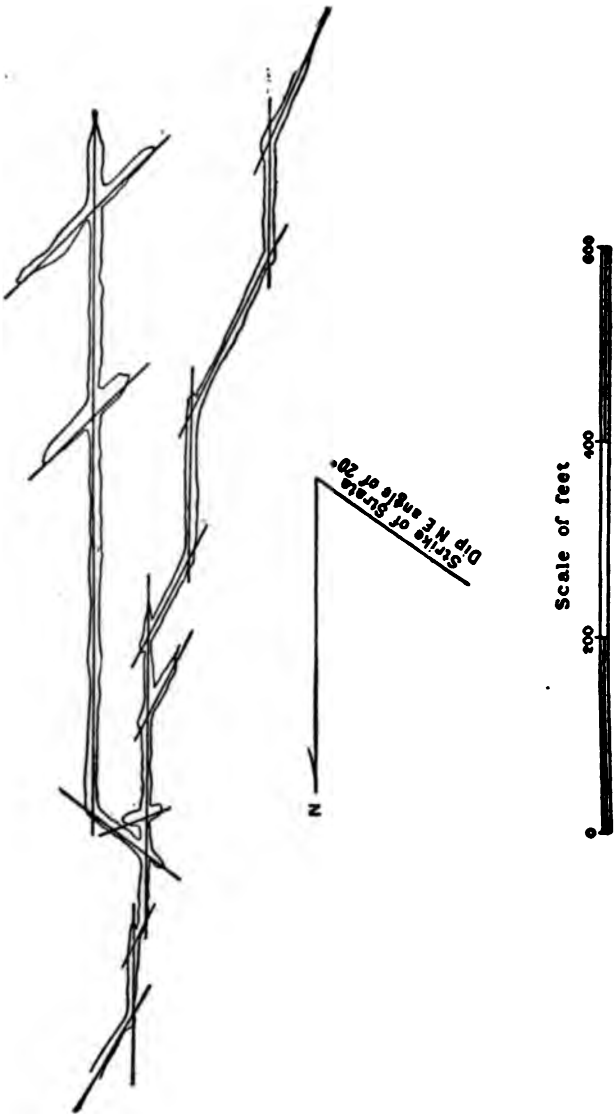


FIG. 151.—DIAGRAMMATIC PLAN OF OREBODIES, AJAX MINE, TINTIC DISTRICT, UTAH. (TOWER AND SMITH)

the sedimentary rocks, Eureka, Mammoth, Godiva-Sioux mountain. In the igneous rock there are many short veins. The contact deposits follow the monzonite border.

The ores consist of pyrite galena, zinc-blende, copper pyrite, and enargite, with a quartz-barite gangue and rich silver and gold minerals.

In the sedimentary rocks the orebodies occur along nearly vertical fractures, replacing the wall rock from a few inches to 50 ft. or more. The ore shoots are very irregular and form great chambers, pipes, pockets, and chimneys as at Bullion-Beck and Mammoth. They lack walls and selvages.

All the ores are the result of deposition by ascending heated waters replacing rocks.

At Copper Mountain, in Box Elder county, close to the Utah-Nevada boundary, there are copper deposits in limestone. The ores occur in a pass across the Pilot range, about seven miles southeast of Tecoma, Nev. The altitude is 7300 ft., or 1500 ft. above the desert plain. The orebodies are in part capped by masses of iron gossan, and extend in a general north-south direction. They occur as irregular masses, presumably connected by ore stringers and fractures, in limestones, dipping eastward, and underlain by a series of quartzite beds. A dike of decomposed igneous rock is found alongside the ore in the deeper workings. The orebodies are incased in alteration clays, the conditions resembling those at Bisbee.

Silver-bearing lead ores, once extensively mined, occur in irregularly parallel vein and cross fissures, near or connected with the copper deposits. The copper ores consist of green carbonate with some oxide and native copper in an argillaceous gangue. The composition is approximately: copper, 7 per cent; iron, 22 per cent; silica, 18 per cent; alumina, 26 per cent; lime, 2 per cent; and silver, 0.3 oz. per ton.

The deposits have been extensively developed, and shipments will begin in 1907.

Washington

The copper product of Washington comes chiefly from the mines situated in the eastern part of the State, though numerous prospects exist in the Lake Chelan region and in the Cascade mountains.

Index District. — There are a number of promising copper districts in the Cascade range. The best-known of them is the Index district, near the peak and town of that name on the line of the Great Northern Railway. There are a half-dozen or more groups of claims within a radius of five miles of the town which have been worked for several years, one of them, the Copper Bell mine, having been equipped with a 20-ton mill to use the Elmore oil process. Several mines are equipped with wire-rope tramways.

In general the veins are narrow and the values spotty; the ore shoots consist of low-grade ore with balls and kidney-shaped masses up to 6 or 8 in. in diameter, of solid bornite. The low-grade ore consists of silicified and somewhat sericitized granite peppered with pinhead specks of bornite. Although apparently a good concentrating ore, it has been found in practice that the bornite is only released when the ore is crushed to 60 mesh or more and that it slimes so badly that only about 40 per cent of the copper is recovered. Usu-

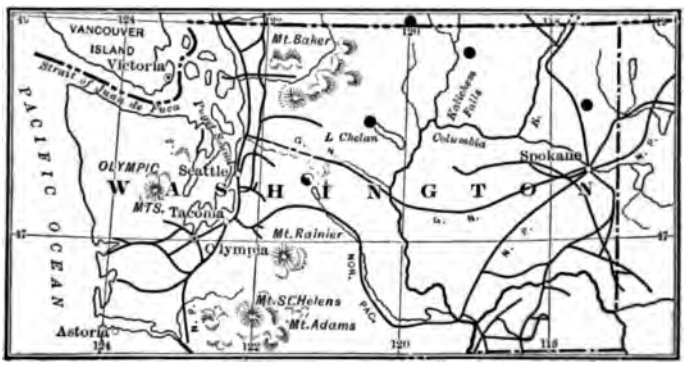


FIG. 152.—INDEX MAP SHOWING COPPER MINES OF WASHINGTON

ally the veins are very narrow seams, often only a half-inch to two inches wide for long distances, widening, however, where ore shoots occur, as at the Copper Bell mine, where there is a chimney 30 ft. across. Outside of the veins there are areas of mineralized rock, but they are patchy and not extensive. The Ethel, Sunset, North Star, and Copper Bell mines are the main properties.[1]

Darrington District. — In the northern part of the State, some 12 miles south of Darrington, the Bornite Copper and Gold Company are developing a deposit in an exceedingly rough and precipitous part of the Cascade range. The ore appears to be in an andesite dike 1000 ft. wide that cuts through the ordinary Cascade granite. The ore

[1] William S. Thyng, *First Annual Report*, Washington Geological Survey, 1901, p. 114.

zone is wide, and streaks of nearly solid bornite and chalcopyrite are found at the contact. A cross-cut tunnel 2300 ft. long has been driven to cut the ore at 1000 ft. below the outcrop. There is a very large tonnage of ore in the form of débris at the foot of a cliff, but in an almost inaccessible place. The ores consist in part of a mixture of bornite with augite and quartz, in part of dense, very fine-grained chalcopyrite in a black schist, and appear to carry barite.

Foss River District. — The Foss river district, near Skykomish, on the Great Northern Railway, shows deposits of high-grade chalcopyrite ore that will be worked when transportation is provided.

The best-developed property is known as the Dutch-Miller group. It is located 11 miles south of the railway at an elevation of 5600 ft. at the extreme head of the middle fork of the Snoqualamie river, on the main crest of the range. The vein is a distinct fissure traceable for many miles across the bare slopes and cliffs of granite. It is marked here and there by an ironstone cap and generally by a rusty outcrop. It is a tourmaline vein with usually well-defined walls and a width of 1 ft. to 18 ft.

The high-grade ore consists of chalcopyrite, pyrite, arsenopyrite, and blende with some siderite and quartz. The vein filling generally consists of a mass of tourmaline in stellate aggregates, often showing scattered particles of chalcopyrite and the other metallic minerals of the veins. In places the vein is like a pegmatite, to which it is clearly allied in origin. The high-grade ore shoot has a length of 40 ft., a width of 18 ft., and has been opened to a depth of 60 ft. below the outcrop. The dip is 68 deg. west, and the shoot pitches south. The ore averages 16 per cent copper in this shoot.

The line of this vein is traceable westward for some miles to Copper and Malachite lakes, where there are said to be several parallel veins showing a tourmaline ore like that of the Dutch-Miller, but carrying bornite as well as chalcopyrite. To the southeast the same line of strike shows bodies of copper ore at Fish lake, eight miles distant, on the Clealum river. The Clipper group of claims shows large bodies of concentrating ore, an impregnated granite carrying bornite and chalcopyrite, and reported to be over 200 ft. wide.

On the Clealum river, 25 miles north of Roslyn on the Northern Pacific Railway, there are great gossan outcrops that extend for miles along the west slopes of Mount Hawkins. The deposits lie in a belt of diabasic lavas, tuffs, and breccias, a mile wide, that runs east and west and has peridotite to the north and south. A narrow belt of altered limestone, the so-called nickel ledge, lies in the serpentine at the contact. Prospects showing copper ores are also found on Negro and Ingalls creeks, southeast of Mount Stuart, in Chelan county.[1]

In the Chelan district there are many large but undeveloped deposits of low-grade ore. The Holden property on Railroad creek, 15 miles west of Lake Chelan, shows an outcrop 100 ft. wide.

The Copper King mine, a property situated 4 to 5 miles from Chewelah, Stevens county, is the chief producer. The ore consists of massive pyrrhotite and chalcopyrite, and is said to occur in a schistose rock with granite near by.

At Chesaw, Ferry county, near the boundary line, several deposits of cupriferous pyrite occur in schistose rocks. The Belcher mine shows an ore of fine-grained, dense, banded mixture of pyrite and chalcopyrite. The district is underlain by diorite[2] and syenite porphyry. The ore-bodies occur in east-west fractures in the diorite, with northerly dip. The ore occurs both in nearly pure bodies and with country rock. The largest shoot in Belcher No. 2 is of massive pyrite ore, and has an extreme width of 80 ft. and is 100 ft. long. Pyrrhotite is abundant in some veins and carries low gold values.

Copper deposits of large size but unknown value also occur in the Stehekin district at the north end of Lake Chelan. The Chelan ores consist of brecciated andesitic dikes containing pyrite, chalcopyrite, and arsenopyrite, and occur in marble.[3] Deposits in syenite occur in King county.

Wyoming

The principal copper-producing section of Wyoming is the Grand Encampment district, in the southern part of the State, extending from the Pearl district of Colorado northward on both sides of the Platte river.

The district has been described by Spencer.[4] The region is one of quartzites and schists, the beds having a prevailing east-west course, and dipping steeply to the north, and being intruded by igneous rocks. The orebodies are reconcentration enrichments along channels, formed by a netted fracturing of the rocks.

[1] George Otis Smith, *Geologic Atlas of the United States*, p. 9 (Folio 108, Mount Stuart).

[2] *Mining World*, January 9, 1904, p. 86.

[3] Kemp, "Ore Deposits of United States," p. 222.

[4] *Professional Paper No.* 25, United States Geological Survey, 1904.

The Encampment district lies north of the Colorado line, some 43 miles south of the Union Pacific Railroad, in the foothills of the Park Range. The region has a complex geological structure. The most prominent rocks are bands of white quartzite running east and west, and separated by bands of conglomerate shale and limestone. The dip is steep and to the south. Diorite occurs in dikes from a few feet to a half mile in width, often running with the bedding of the other rocks. The

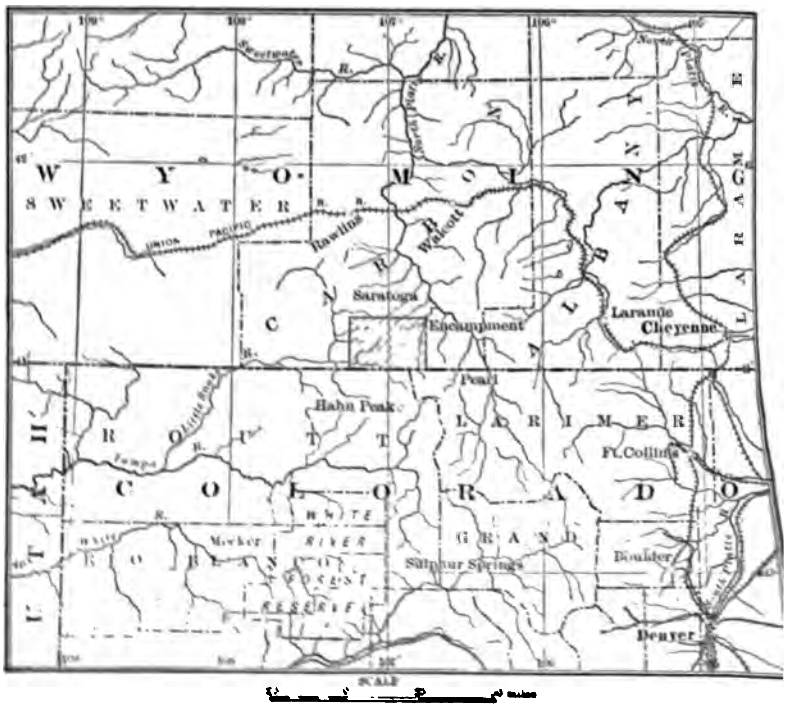


FIG. [illegible] INDEX MAP OF WYOMING SHOWING LOCATION OF ENCAMPMENT DISTRICT

schistose rocks embrace granite gneiss, younger than the more abundant hornblende gneiss. The rocks are of pre Cambrian age.

The copper deposits are of three classes: [illegible] copyrite and pyrite deposits in fresh, undecomposed rock as [illegible] aty masses interfoliated with the schist, often without vein [illegible] wi[illegible] and small amounts of carbonates. Such deposits [illegible] le value [illegible] (2) Copper deposits of copper gla[illegible]

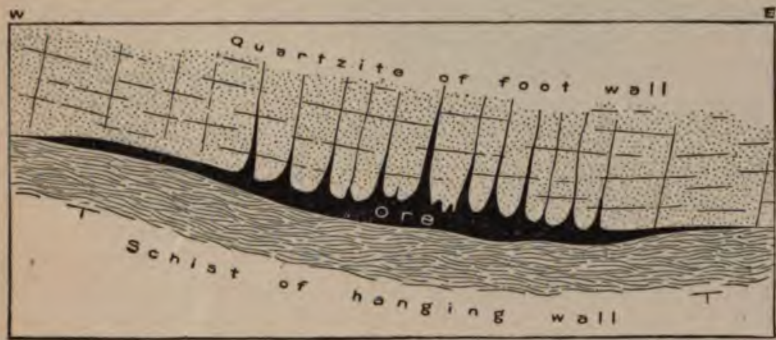


FIG. 154.—IDEALIZED HORIZONTAL SECTION OF OREBODY, FERRIS-HAGGARTY MINE, SHOWING GENERAL CONVEXITY TOWARD THE SOUTH AND THE FILLING OF NORTH-SOUTH FRACTURES. (SPENCER)

FIG. 155.—IDEALIZED VERTICAL NORTH-SOUTH SECTION, FERRIS-HAGGARTY MINE, ACROSS THE OREBODY, SHOWING CONVEXITY AND IRREGULAR DIP. (SPENCER)

with or without chalcopyrite. The deposits of the Ferris-Haggarty, Doane, and Charter Oak are of this latter class. At the last-named mine the rock is granite and diorite, and the deposit irregular; at the others there is greater regularity, and the orebodies occur inclosed in quartzite of sedimentary origin, in zones of shattered rock which follow the bedding planes. (3) Copper pyrite in a matrix of quartz accompanied by calcite and siderite, or by feldspar, the sulphide occurring in bunches. Such veins follow the schistosity, and the quartz masses may be 50 ft. wide and more than twice as long, but are usually a series of thin, disconnected lenses of low grade.

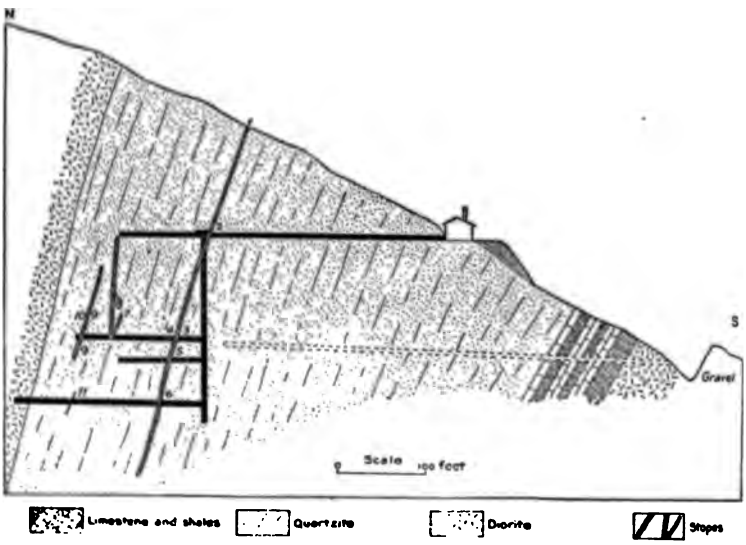


FIG. 156. SECTION OF DOANE MINE, WYOMING. (SPENCER)

In the Doane mine the orebody lies between steeply dipping schists and quartzites, the former lying above the ore. The ore consists of chalcocite and chalcopyrite impregnating and replacing crushed quartzite, this rock forming the gangue. Much of the ore requires concentration. The orebody is 250 to 300 ft. long, and varies from a few inches at the end up to 30 ft. in thickness in the middle. The schist hanging wall is very regular; the footwall very irregular, being governed by the amount of brecciation or fracturing of the quartzite. But one pipe of ore has as yet been found.

The orebody of the Ferris-Haggarty mine is of the same type as the

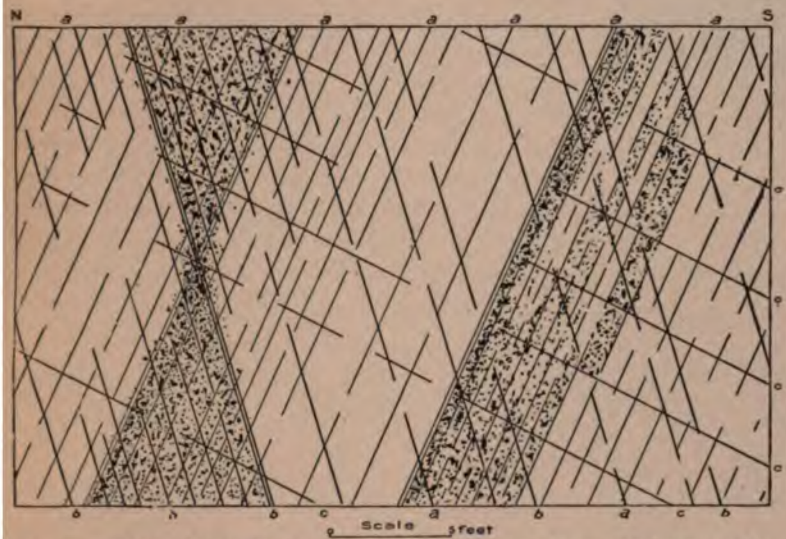


FIG. 157.—DOANE MINE: DIAGRAMMATIC CROSS-SECTION IN LOWER PORTIONS OF STOPES 7 AND 8, SHOWING OCCURRENCE OF THE COPPER SULPHIDES IN BRECCIATED QUARTZITE FORMED ALONG INTERSECTING JOINT SYSTEMS. *aa*, BEDDING PLANES AND PARALLEL JOINT FRACTURES; *bb*, STRONG SYSTEM OF JOINTS; *cc*, SUBORDINATE JOINTS; DISTRIBUTION OF SULPHIDES INDICATED BY STIPPLING. (SPENCER)

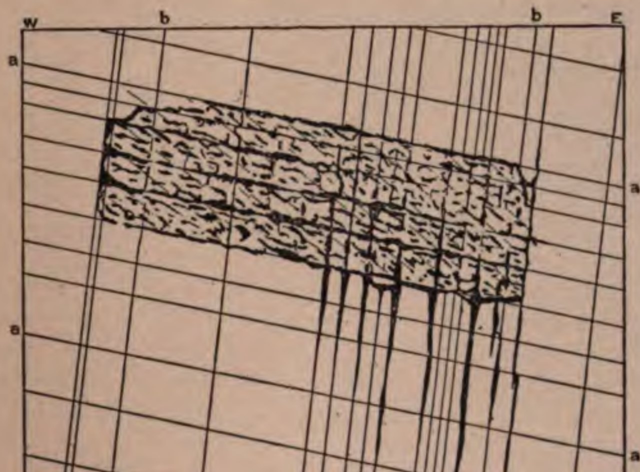


FIG. 158.—DOANE MINE: HORIZONTAL SECTION OF OREBODY IN STOPE 9, ABOUT 25 FEET ABOVE 115 FEET LEVEL, SHOWING RELATION OF OREBODY TO THE LAYERS OF QUARTZITE AND THE NORTH-SOUTH FRACTURES. *aa*, STRATIFICATION; *bb*, NORTH-SOUTH CROSS FRACTURES. (SPENCER)

Doane. The ore is glance, with lesser amounts of chalcopyrite, bornite, and rarely of covellite. The orebody is an elliptical "pipe" lying in a bed of quartzite, dipping steeply to the north, the ore shoot having a wavy pitch to the west, as shown in Fig. 155.

The Rambler mine, 20 miles from Encampment, is of a different character. The orebody lies in diorite, and the ore consists mainly of covellite, carrying platinum, iridium, and other rare metals in appreciable amounts.[1]

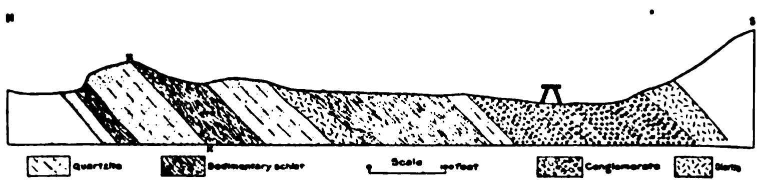


FIG. 159.—SECTION OF BEDDED FORMATIONS ON RIDGE NEAR FERRIS-HAGGARTY MINE. THE SO-CALLED "CONTACT" HORIZON IS MARKED BY CROSSES

The Bighorn mountains contain a few copper deposits. According to Darton,[2] oxidized ores of copper occur in the granite region, on Beaver creek near Bull Camp and Okie's Store. Small quantities of high-grade ores occur in quartz veins near diabase dikes, but the deposits are of no economic importance. A copper-bearing quartz vein, traceable for three miles, exists southwest of Walker prairie and the south fork of Wolf creek. The vein is 15 ft. wide, but too low-grade to work under existing conditions.

The granite area of the Bridger range exhibits copper veins. One of these, southwest of Deranch, shows an ore shoot of high-grade oxide and sulphide ore.[3]

[1] J. F. Kemp, "Mineral Resources," 1903, United States Geological Survey, 1904; S. F. Emmons, "Contributions to Economic Geology," *Bulletin* 225, United States Geological Survey.

[2] "Geology of the Bighorn Mountains," *Professional Paper No.* 51, United States Geological Survey, 1906, p. 114.

[3] Darton, *l.c.*, p. 114.

INDEX